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TEXT-BOOK OF BIOLOGY.

PART II.—INVERTEBRATES AND PLANTS.



Univ. Corr. Coll. Tutorial Series.

TEXT-BOOK OF BIOLOGY.

BY

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WITH AN INTRODUCTION

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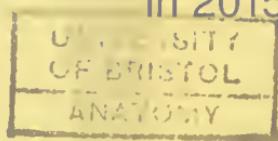
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PART II.—INVERTEBRATES AND PLANTS.



LONDON : W. B. CLIVE,
UNIVERSITY CORRESPONDENCE COLLEGE PRESS.
WAREHOUSE: 13 BOOKSELLERS ROW, W.C.

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PREFACE.

VOLUME I. of the "Text-Book of Biology" dealt mainly with the morphological aspect of the science. We laid stress on the resemblance between four related types. Where they differed our analysis was directed to clear up the difference, and all our comparisons pointed to identification. The main idea of the book was the idea of a family likeness, of features inherited in common ; in a word, *heredity*. In this volume we have in the Flowering Plant, Pine, and Fern three obviously related forms that repeat this lesson from the botanical side. But the whole range of the types dealt with in this book hardly admits of the same unity of treatment as the subject-matter did, of Part I. The pedigree that will link Pine and Bladder-wrack, *Amoeba* and the Crayfish, has not yet been made out. If it had, it could scarcely be rendered evident without at least quadrupling the number of types we study. We can only infer from the plain evidence of blood relationship between Frog and Rabbit, and between Flowering Plant and Fern, that a wider knowledge would make it clear to us that all living things had a common ancestry, and would show that under various disguises there lurked an essential unity of inherited character. But

with the types at our disposal this must remain an inference only. By the study of these types alone such a connection is practically impossible.

Hence in this volume we have treated our types, with the exception noted above, with little or no attempt to notice resemblances. We have here samples of the most divergent forms that life has assumed. The student should notice how the common phenomena of life, anabolism and katabolism, the integration and disintegration of protoplasm, go on amid the most divergent surroundings ; the stress is throughout on the contrasts. Under the Flowering Plants in particular we call attention to the adjustment of structure to the conditions of life ; but throughout this relation of the organism to its surroundings is borne in mind. The former volume was essentially morphological, and considered each type as related to other and nearly kindred types. Here for unity of plan adapted to different ends we have diversity of plan, sometimes attaining very similar ends. This is particularly brought out in a comparison of the Crayfish with a Vertebrate.

It is suggested that the beginner should commence the study of this book *at earliest* after that section of Part I. devoted to the Rabbit has been read. The whole of Part I. should be finished before our chapters upon Hydra, Mussel, Earthworm, and Crayfish are begun. All that we have said in Part I. of the value of drawing and of practical work applies with equal or greater force here. We are dealing again with things, and now, in the case of the botany, with things that

are at hand everywhere. Such a book as this should be a guide standing behind the student, as it were, and pointing over his shoulder to what he has to see for himself, not standing in front of him and deceiving him with the implication that the figures in its pages are truer to nature than Nature herself. Accordingly we have made our figures, and particularly those of common flowers and fruits, as simple and diagrammatic as possible, mere keys to the actual specimens that the student must obtain.

Read in the order thus indicated, and *with an honest performance of the practical work* prescribed at the end, the student will, I hope, find this text-book a sound introduction to biological science. But he must bear in mind that the work is condensed, and that he cannot afford to take any liberties of omission with the text. It is an attempt to teach the mere elementary principles of biology, and we have studiously avoided anything either premature or useless. A considerable experience with examination candidates shows that nothing is so conducive to pure cram as a too detailed treatment. There is a type of examinee, unfortunately only too common, whose one idea seems to be to get as many degrees and diplomas and as little knowledge as possible, and in no way can this purpose be aided more powerfully than by giving him a great heap of disconnected facts, and trusting to a rudimentary discrimination to discover the principles of the science that lie beneath. This book is written in the persuasion that facts that do not clearly bear upon the sustaining laws of organic evolution, or upon physiological prin-

ciples, are so much useless lumber to the elementary student. The only effectual way to defeat the crammer—the ambition of every teacher for university examinations who is worth his salt—is to omit such things altogether, to leave him nothing but what unavoidably challenges comparison and thought, and points certainly and unequivocally towards the wider laws of the subject.

H. G. WELLS.

July 1893.

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VEGETATIVE ORGANS OF THE FLOWERING PLANT.

I.—*The Nutrition of a Flowering Plant.*

§ 1. If the reader were requested to name the first ten plants that came into his mind, the chances are that nine out of the ten would be plants consisting, in addition to the flowers and fruits, of the following parts : of a **root**, spreading its branches through the soil ; of a **stem**, rising, more or less, above the ground and perhaps branching ; and of **leaves**, borne upon the stem. Some plants he might think of which had only a slight representation of the stem —the primrose or daisy, for instance, in which the only stem apparently present is the short stalk bearing the flower ; but these would not form a very important part of his list. And in all cases, doubtless, the leaves would have a characteristic green colour (**chlorophyll**), the roots would be devoid of that colour, and the stem might or might not display it.

§ 2. Such observation as any one might make in the course of a walk in the country would show that there was a very close connection between this green colour, light, and the life of the plant. On the greensward, in the sunlight, vegetation grasses, trefoil, buttercups and daisies, for instance, would be abundant, but directly the shadow of trees was reached the herbage would cease more or less completely. Any one who has walked through a spinny of fir trees will recall how entirely devoid of vegetable life was the ground beneath their dense shade. In the case of such trees as the beech the shadow is less profound, and we may find ferns, nettles, and other plants growing. And similar results will be noted in a thick hedge. Any one who has ever peered into a hedge will

remember that it is not a solid mass of green, but a tangle of branches displaying an outer coating of dense greenery to the light. The connection of light and the green colour, or chlorophyll, as indispensable to the life of the plant, is thus very clearly suggested, and the importance of the stem in raising the leaves of the plant above those of its fellows, and enabling it to intercept and secure for its own purposes this necessary light, that would otherwise fall upon them, is also manifest.

§ 3. The most obvious, but not the most important, duty of the root is evidently to fix the plant to its footing in the sunlight. This could be effected very well if the root were simply a spike sticking into the ground; but as a matter of fact roots are almost always complex branching networks, and their complexity is always more or less plainly proportionate to the branching of the stem and the amount of leaves it bears. Further, throughout the life of the plant the rootlets (smaller root branches) are continually thrusting themselves, often with considerable force, through the ground, and connecting the plant with fresh soil; and this alone would lead an observer to suppose that there was also some relation between the spreading of the roots and the nutrition of the plant. Such, indeed, is the case: the roots continually, except in winter, and the green parts above so long as sunlight reaches them, are engaged in obtaining food for the plant from the soil and from the air.

§ 4. In order to understand the working mechanism of the plant it will be convenient to examine the structure of one in detail. Examined microscopically, all parts of an ordinary plant are found to be made up of certain structures called **cells**, or of minute tubes called **vessels**, or of other structures derived from cells. These cells vary much in shape and structure, but they agree among themselves, and differ from what is styled the "*cell*" of an animal body* in being enclosures in a **cell wall**. At first

* "Biology," Part I., p. 21.

every cell has a cell wall of a substance called cellulose (consisting of carbon, hydrogen, and oxygen, and having the two latter elements in the proportion of H₂O). Within this wall is a mass of transparent colourless viscid substance, the protoplasm, of variable density in different parts, and having a denser portion, the nucleus. The protoplasm may be observed sometimes to have a streaming motion within the cell. The whole of the protoplasm of the cell and the cell wall are saturated with water holding sugar and other substances in solution, and called the cell sap. Such a cell as this (Fig. I., Sh. I.) would be found near the growing point of a plant. The protoplasm is the living and active principle of the plant, and consists of a complex union of carbon, hydrogen, oxygen, and, in addition, nitrogen and sulphur. The protoplasm of adjacent cells is continuous, the cellulose walls being perforated by fine threads. (Compare the processes of bone and cartilage cells in animals.) The nucleus appears to be the directive centre of the cell's growth and activity. Such a cell is capable of division into two cells; and such division is invariably preceded by the division of the cell nucleus.* A cell with abundant protoplasm, and capable of division, is called *meristematic*, and a part of a plant consisting of a number of meristematic cells,

* Nuclear division, in the case of the tissue cells of the higher forms of both animal and vegetable, is by no means a simple division of the homogeneous nucleus, as it would appear to be in the Amoeba. The undividing nucleus, examined with a very high power, is seen to consist of a general protoplasmic substance (*achromatin*) through which spreads a network of denser strands which stain more deeply with reagents (the *chromatin strands*). In division this network breaks up into spiral rods, which make their way to the equator of the nucleus, and then form a star-like body (*aster*). The rays of this star split longitudinally, so as to form two stars, which move away from each other towards the poles of the nucleus (*dyaster*). Between the two stars, as they separate, protoplasmic filaments may be seen extending, forming a spindle-shaped body—the *nuclear spindle*. At the equatorial plate of this nuclear spindle, in the case of vegetable cells, small dots of substance—the *microsomata*—appear, and run together at last to form the partition wall of the two cells, as the stars of the dyaster break up again into spiral rods, and ultimately reconstitute the chromative network of the nucleus. This process of cell division is called *karyokinesis* (Fig. VIII., Sh. II.).

as, for instance, the growing point, is said to consist of **meristematic tissue**.

§ 5. But, in the greater portion of the plant body, the cells will be found to be considerably altered from this typical condition. They will be, in most cases, much enlarged, and the increase in the amount of the protoplasm within them has often failed to keep pace with their increase in size. Large cavities filled with cell sap will consequently have appeared in it (Fig. II., Sh. I.); these are **vacuoles**; and the protoplasm of the cell is said to be vacuolated. In most vegetable cells this vacuolation occurs, and the protoplasm forms a mere lining to the cell wall, and is spoken of as the *primordial utricle*. In some cases, the entire cell contents will have disappeared, and the modified cell will be filled with cell sap or air. Or, again, in the green parts of plants there will have appeared certain small grains in the protoplasm, which will be coloured green by the green colouring matter, *chlorophyll*, already referred to.* These are the **chlorophyll grains**. Other cell contents we shall notice later. The cell may be round, or, by pressure against its fellows, polyhedral in shape, or elongated to form a prism, in all of which cases it is called a **parenchymatous cell**; and tissues composed mainly of such cells are **parenchyma**. Or it may become elongated, *pointed sharply at*

* Such small grains of protoplasm in the general protoplasm of the cell go by the name of plastids. Those that form chlorophyll are called *chloro-plastids*, which is therefore a synonym for chlorophyll grains. Colourless plastids are called generally *leuco-plastids*. They occur, for instance, in underground parts, where sugar is being re-converted into starch for storage purposes, and the chlorophyll grains, before chlorophyll is formed in them, are also leuco-plastids. Plastids which form other colouring matters, as, for instance, those forming the yellow of plant petals, are called *chromo-plastids*. Leuco-plastids may become chloro-plastids, and either leuco-plastids or chloro-plastids chromo-plastids. Celery, for instance, when exposed instead of being earthed up to exclude the light, becomes green through the development of chloro-plastids, and in the autumn the chloro-plastids of leaves about to fall become chromo-plastids. Plants which, like celery, are bleached by deprivation of light, and which therefore have leuco-plastids in the place of chloro-plastids, are said to be *etiolated*.

the end, and fibrous (Fig. III.), when it is a *prosenchymatous cell*. Or a line of cells running through the plant may, by the absorption of their party walls and contents, become a continuous tube, when we have what is called a **vessel**. These terms are convenient, though in practice these three divisions are by no means sharply defined. The change of meristematic to this, that, and the other kind of cell is called **differentiation**.

§ 6. The **cell wall** may remain simply a thin wall of cellulose, or it may become thickened by the addition of fresh matter to its inner aspect, layer by layer, through the activity of the contained protoplasm. This **cell thickening** may be simply additional cellulose, as in the cells of the date stone; but far more frequently it is cellular impregnated with a substance called **lignin**, which renders it firmer, and alters its properties in other ways. Another similar substance—*suberin*—impregnates the thickening of those cells that build up the tissue called cork. Corky thickening, and usually cellulose, when they are spread over the inside of a cell wall are distributed evenly; but lignified thickening is commonly laid down in bands and patches over the surface it thickens—it scarcely ever forms a *complete* inner coating to a cell or vessel. We may have it so abundant that only small dots or circles of the original wall remain unthickened, in which case we have pitted cells or vessels, or it may be less abundant, and forming a spiral thread (spiral thickening), or only at intervals, constituting isolated rings (annular thickening). Types of all such thickenings are shown upon Fig. IV., Sh. I.

§ 7. How these various forms of cells are arranged to co-operate in the life of a plant we will now proceed to consider. But first we may notice one or two facts in the chemical composition of a plant. Evidently (§ 4) carbon, hydrogen, oxygen, nitrogen, and sulphur are necessary for a plant's nutrition and growth. Chlorophyll, besides all these elements, requires iron as an essential condition to its formation; so that this must also be added to our list for green plants. Experiment seems to show that sodium,

potassium, calcium, magnesium, are also indispensable, directly or indirectly, to the welfare of the plant, and sometimes chlorine and silicon. These elements, excepting the carbon, are commonly obtained by the plant, in combination as simple inorganic salts, from the soil. The carbon is obtained by the agency of the chlorophyll corpuscles of the green parts in a special manner, to be presently described—from the small amount of carbon dioxide (.04 per cent.) always present in the air.

§ 8. In the capacity of a green plant to live upon simple inorganic compounds we have a very striking difference from the state of affairs in a higher animal. In "Biology," Part I., the rabbit is described as a machine for the release of energy by the evolution of simple and stable from complex and unstable compounds. It is an essentially destructive machine, requiring to be fed with carbohydrates or hydrocarbons and proteids ("Biology," Part I., Rabbits, § 17). The plant, on the other hand, is, on the whole, largely constructive: it receives and stores up far more energy than it gives out. A certain amount of kataboly of course occurs in a plant; a germinating seed, a plant growing in the night, are doing work and destroying material, consuming oxygen, and disengaging katastases, like an animal. But in the daylight the plant's activity is relatively less than, and entirely marked by, its receptivity; and the balance of the entire account is on the side of anaboly. An animal is always decomposing; on the other hand, a plant in the sunlight is receiving energy and manufacturing. The source of this balance of energy in the plant's favour is the radiant heat and light of the sun, and it is apparently utilised in the following way.

§ 9. Fig. X., Sh. I., shows a cross section of such a leaf as that of the sunflower. It consists chiefly, the reader will see, of parenchymatous cells. In the centre is one of the veins of the leaf; of these we shall speak more fully presently. *Ep.* is the *epidermis*, a single layer of cells with a special thickening of their outer cell walls; the *cuticle* (*cu.*), practically impervious to air and gases. The under

epidermis, it will be noticed, is perforated by apertures, *the stomata (sta.)*. The mass of the leaf is the *mesophyll (ms.)*. This in most leaves differs towards the upper and under sides; in the upper it is columnar in form, without spaces between the cells, and is called *pallisade parenchyma (pal.)*. Towards the under it becomes looser in texture, and irregular spaces (intercellular spaces) appear between the cells, the *spongy parenchyma (spg.)*. As a consequence the upper side of a leaf is commonly greener than the under. All these cells except the epidermal* contain chlorophyll corpuscles. In the light carbon dioxide is continually diffusing into the leaf through the stomata to the intercellular spaces, and thence through the thin mesophyll cell walls to solution in the cell sap, and so to the chlorophyll corpuscles. The oxygen of the CO_2 is continually being released by these and diffusing out again into the air. Starch, a carbohydrate ($\text{C}_6\text{H}_{10}\text{O}_5$), is the first visible product of this process ("Assimilation,"† or better, Carbon Assimilation), and appears in increasing quantities in the chlorophyll corpuscles, the longer the leaf is exposed to the light (see Fig. VIII., Sh. I.). We really know nothing of the details of this process; we simply know that the chlorophyll corpuscle is able to bring about this result, but *how* we cannot say. The net result of the whole is that the carbon of the dissociated carbon dioxide has been combined with the elements of water to form starch.

§ 10. The starch is visible because it is insoluble in cell sap at its ordinary temperature. It would seem to be converted into some form of the soluble carbohydrate, sugar, which diffuses slowly from the assimilating regions inward. To effect this change some ferment similar to the ptyalin of saliva must be formed by the plant. This sugar may pass through the stem to the growing point at once,

* The "guard cells," one on either side of each of the stomata, contain chlorophyll.

† The word has evidently a different and narrower meaning in botany than in animal physiology, where it implies the taking up of any kind of nutritive material *by the tissues*. Many botanists use assimilation for the elaboration of all food material.

to be there converted, probably after intermediate changes and recombinations, into the permanent and useful form of carbohydrate, cellulose ; or it may pass to some convenient part of the plant, the stem or the root, and be there reconverted into starch and stored in the cells for future use.

§ 11. We have thus four typical forms which carbohydrate may assume in plants ; its first visible form, starch ; its final form, the cellulose of the cell wall ; its transit form, sugar ; and its storage form, which is also usually starch. There are two chief types of sugar in the plant body, cane and grape sugar. The latter is distinguished from the former by giving a black precipitate with Fehling's solution (see Appendix on Practical Work). The starch grain (Fig. XIII., Sh. I.) usually presents a centre of growth, *hilum*, among which lines of growth are concentrically arranged. Starch is usually, but by no means the invariable, storage form of carbohydrate. In the date stone cellulose is stored ; in the beet root, cane sugar ; in the dahlia root occurs a substance, *inulin*, which is precipitated in very characteristic spherical cell aggregates by the addition of alcohol. In many seeds stored hydrocarbons (*i.e.*, fats and oils) replace the carbohydrates, just as they do in the food of many animals. Most nuts, and especially such a type as the castor oil nut, are examples of this. (Compare "Biology," Part I., § 17.) It is also the case in the substance of fungi and *Vaucheria*.

§ 12. Solution of iodine stains starch blue and cellulose yellow. Cellulose may be stained blue by iodine after dilute H_2SO_4 . Sugars and inulin are precipitated by alcohol from solution, grape more readily than cane.

§ 13. The details of the formation of proteids and the character of their transit forms are by no means understood so clearly as the corresponding facts respecting the hydrocarbons. Their final form is of course protoplasm. The nitrogen and sulphur, the hydrogen and oxygen, neces-

sary for the plant's nutrition enter by the roots as a weak solution of salts, pass up by the wood (xylem) of the stem, and are spread over the leaf by means of the veins. The excess of water evaporates through the stomata, and its passage out of these apertures is called **Transpiration**, the substances brought up by the water in solution remaining to be elaborated into organic compounds. It appears probable that the necessary sulphur frequently enters the plant body in combination as sulphate of lime, and that after the decomposition of this compound, the lime being of no great use to the plant combines with organic acids and is precipitated in its substance. Bunches and bundles of needle-like crystals of oxalate of lime certainly occur in many leaves and stems, and are called *raphides*, as in the bluebell. Other more massive crystal groups may be seen in the leaves of the fig (*cystoliths*). Nitrogen reaches the plant in nitrates and salts of ammonia ; hydrogen and oxygen in water, and the former in ammonia and the latter in salts and other compounds; the other elements occur as phosphates, sulphates, and other salts.

§ 14. Formed proteinaceous matters like bodies in the carbohydrate and hydrocarbon sections may assume a considerable variety of store forms. Their final form and destiny in the plant is typically protoplasm, as that of the starch and oil group is cellulose. **Aleurone grains** (Fig. XIV., Sh. I.) are roundish granules of variable size —largest in oily seeds. They often contain peculiar bodies, the *crystalloids*, which would appear to be crystallised or quasi-crystallised proteinaceous matter. *Globoids* are round concretions of phosphate of lime and magnesia, which almost invariably accompany aleurone grains, but of which the physiological import is not clear. They may have a connection with the fermentative return of the stored proteids to their transit form. The transit of formed proteids is especially the function of the tissue called the phloem, to be presently described.

§ 15. Thus far we have noticed three main categories of bodies in the plant.

- (a) i. CELLULOSE,* forming the cell wall.
- ii. Its transit form—sugar.
- iii. Its storage forms; starch, or cane or grape sugar, inulin (dahlia), or cellulose (in the date), or, as a substitute, oils and fats.
- (b) i. PROTOPLASM (the same elements in the presence of iron also form chlorophyll).
- ii. Proteids are allied nitrogenous bodies in transit (in the phloem?).
- iii. Storage forms; aleurone grains, crystalloids.
- (c) CELL SAP, that is to say, water, with various and variable substances dissolved in it, soaking every part and forming the medium of transit in all cases.

§ 16. We have now to notice a fourth, but extremely heterogeneous series of substances. The exchange of gases that goes on between the air and the plant when it is in the dark, or when seeds are germinating, is, as has already been noted (§ 8), the reverse of what occurs in the day. At the growing point of a stem or root and in the seed underground there is no assimilation, but kataboly is in active progress. Oxygen is taken up by the protoplasm and kalastases formed. For this absorption of O and evolution of CO₂, the term **Respiration** is used. In "Biology," Part I., Chapter I., we have laid down the statement that when living material acts, kataboly occurs, and not only CO₂ but H₂O, and a nitrogenous waste material (and one containing sulphur), are formed. A plant would appear to be capable within limits of consuming its own katastases again; at any rate, we never find any elaborate organs specially for excretion and respiration as we do in animals. But we find in the plant body a large series of low nitrogenous bodies for the presence of which it is sometimes difficult to account. There are the resins, the "alkaloids," and the pigments and crystalline bodies that are shed in the autumn leaves. Galls caused by insects are frequently filled with substances

* *Mucilage* is a modification of cellulose which occurs in such seeds as the linseed, and has the property of swelling up to a sticky slime in water.

SHEET 1.

1. Meristematic cells.
2. Vacuolated cells.
3. Prosenchymatous form of cell.
4. Annular (to left) spiral and pitted (to right) vessels.
5. Cork cells.
6. Sieve tubes.
7. Cells from upper side of leaf.
8. Chlorophyll grains after exposure to light.
9. Laticiferous vessel.
10. Cross-section of leaf through a rib, showing multicellular hairs.
11. Section immediately beneath, and, 12, deeper beneath the skin of a young potato; 11 shows leucoplastids (lc.) and incipient starch grains; 12, the starch grains and their lines of growth.
13. Pea starch.
14. Cells from castor oil nut, showing large aleurone grains; (a) in weak glycerine, (b) in strong, (c) with the grains destroyed by sulphuric acid.
15. Crystals (a) from fig. (b) from a bluebell stem (Raphides).
16. Schizogenous resin passage (as in Pine or Ivy).

c.w., cell wall. *cu.*, cuticle. *cr.*, crystalloid. *ep.*, epidermal cells.

chl., chlorophyll grains. *g.*, globoid.

h., hilum (growth centre) of starch grain.

n. or *ne.*, nucleus.

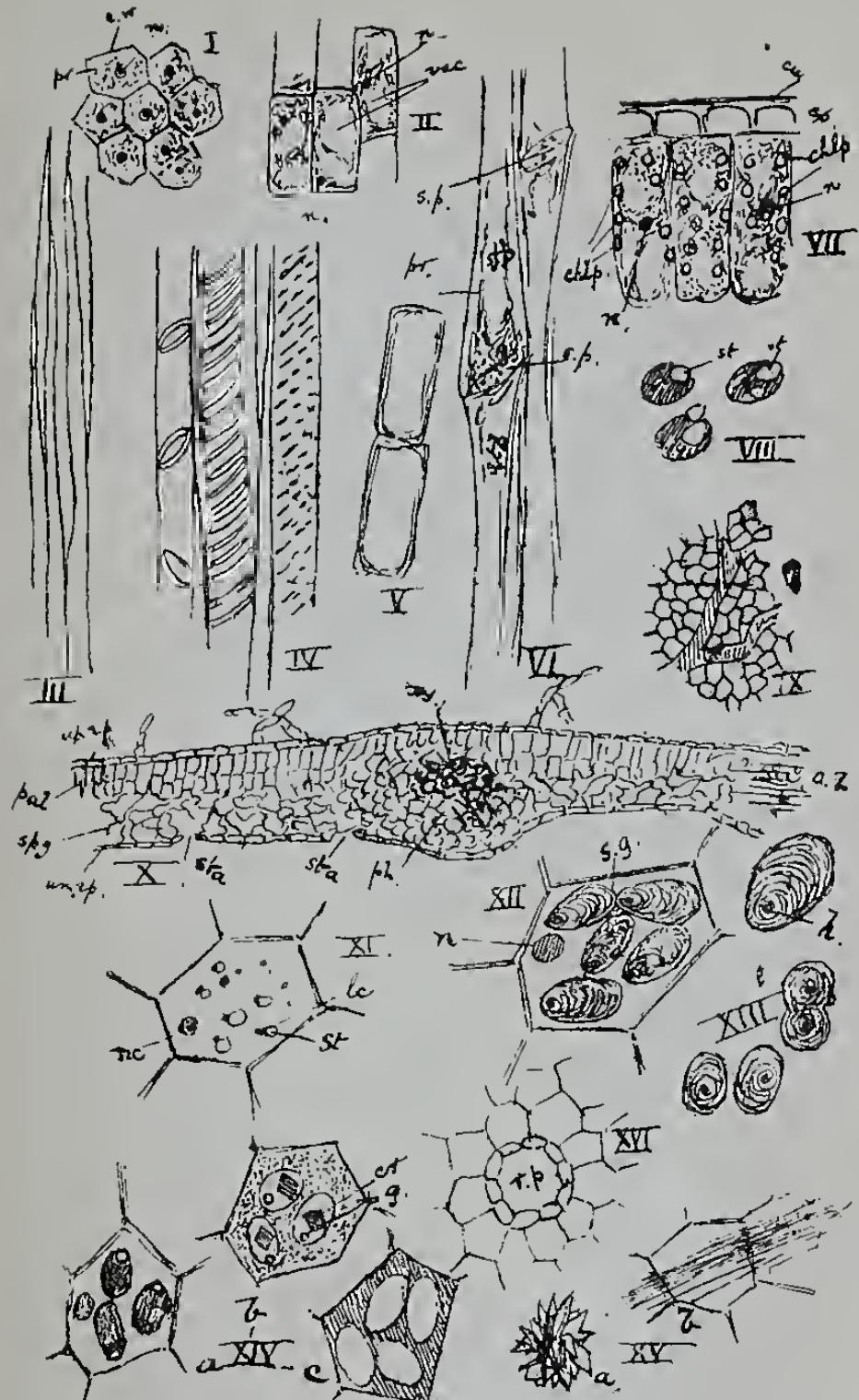
ph., phloem (or leaf vein).

pr., protoplasm. *pal.*, palisade parenchyma. *spg.*, spongy parenchyma.

s.p., sieve plate. *s.tb.*, sieve tube. *st.*, starch. *sta.*, stoma.

vac., vacuole. *xy.*, xylem of leaf vein.

To face page 10.



of this kind, and they are largely utilised for special purposes in special cases; as protective poisons, for instance, or the colours or odoriferous products of flowers. The raphides, of which mention has already been made, are a special example of such bodies, not useful, or only secondarily utilised by the plant, but the formation of which is involved in its activity.

§ 17. To some of these substances the term **secretion** is applied. **Glands** are spaces formed by the separation of cells so as to leave an *inter-cellular* cavity filled with secretion. Such glands are to be found, for instance, just under the outer layer of orange peel; the pungency of the secretion acts as a protection for small animals that would otherwise consume the fruit without scattering the seed. Long tubes formed by a similar separation between cells are called schizogenous vessels (Fig. XV., Sh. I.). The resin passages of the pine tree or ivy leaf are such schizogenous vessels. In Euphorbiaceae* occur vastly elongated and branching cells containing a milky substance called latex. These are the **laticiferous cells**. Throughout the root of the dandelion (Fig. IX., Sh. I.) occur tubes with similar contents formed by the coalescence of long strings of parenchyma cells, styled **lactiferous vessels**. Such vessels as these last are called *lysogenic*, as distinguished from schizogenous. It is necessary for the student to differentiate clearly in his mind between such vessels as these, and the vessels with lignified walls of the xylem of the vascular bundles to be presently described, which serve for the passage of water. *Idioblasts* are *cells* in which such waste matters, as here described, are retained. They occur, for instance, in the leaf of the fig, where they contain crystalline aggregates.

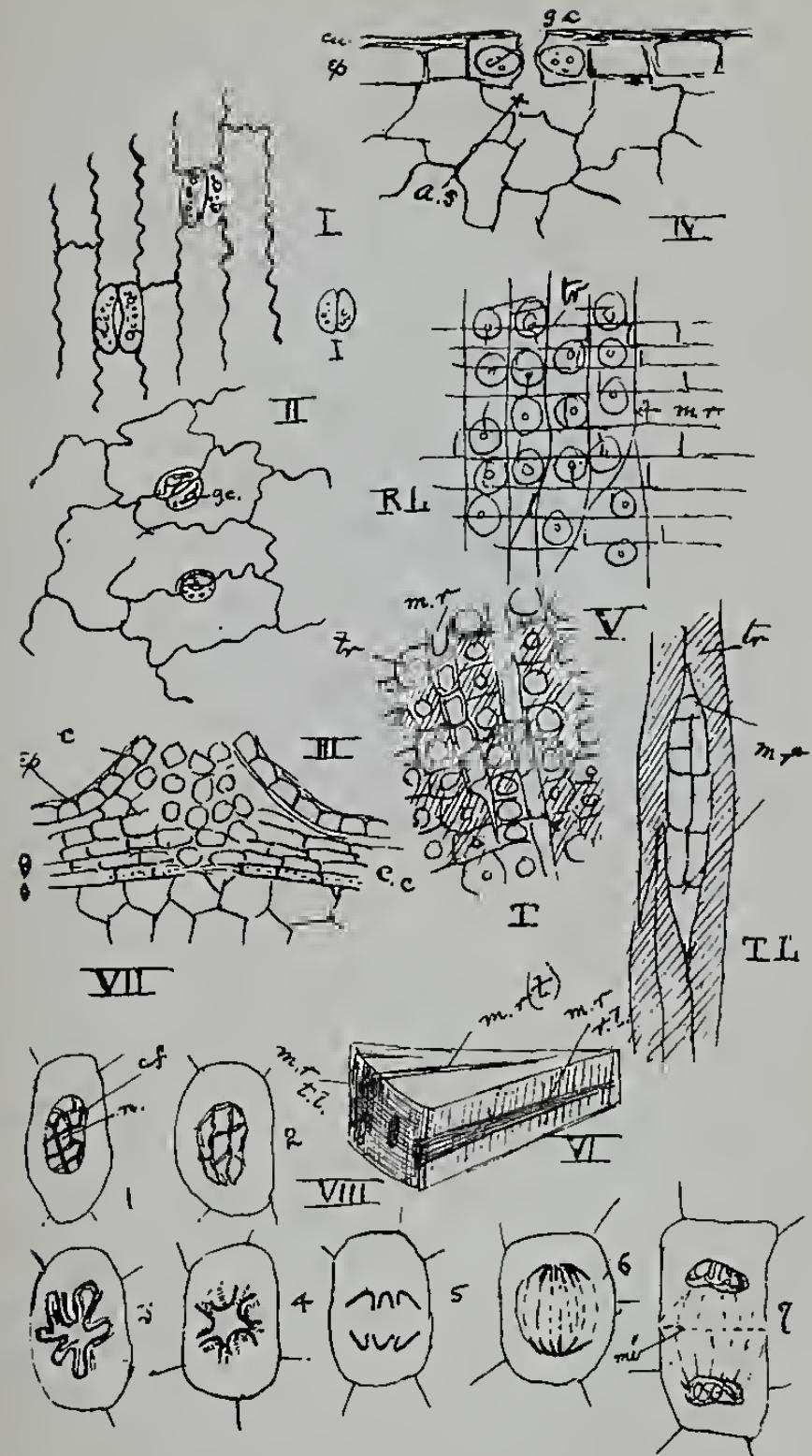
§ 18. A few words may now be said of the general structure of the stem and root, though the matter will be dealt with more fully in subsequent chapters. The very young stem is at first, of course, a mass of *meristematic*

* The peculiar and very common green *spurge* is the best example.

tissue; very early in its development, however, while a large portion of it may remain parenchymatous, (fundamental tissue), strands of lignified and other peculiarly modified cells appear in it called the vascular or fibro-vascular bundles. These are variously arranged and of variable constitution in different cases, but they always contain two constituents; the phloem and the xylem. The distribution in the case of such a plant as the sunflower is seen in Figs. III. and VIII., Sh. V. The phloem (bast) invariably contains (*a*) long tubes called *sieve tubes*, vessels interrupted at intervals by peculiarly perforated partitions, the *sieves* (Fig. VI., Sh. I.), and (*b*) parenchyma. It may also include (*c*) lignified prosenchyma. The xylem (wood) is a more variable part; it typically includes elongated lignified cells, (*a*) lignified prosenchyma (tracheïdes and sclerenchyma), (*b*) some parenchyma, and in all true flowering plants (using the phrase to equal Angiosperms), (*c*) true continuous vessels. (Compare carefully Fig. II., Sh. VI.) It is through the xylem that the transpiration current ascends to the stomata. The phloem, with its sieve tubes, must be of essential importance in the plant scheme, since it is never absent from the higher plants, but the nature of its share in that scheme has only recently been clearly formulated. It is fairly certain that the sieve tubes form the channel for the distribution of formed proteids. The characteristic sieve tubes contain a considerable amount of protenaceous matter, and in winter time there are plugs of this against the sieves. The ordinary parenchyma of the phloem functions in the passage of formed carbohydrates. Passing from the stem to the root (Ch. IV.), the xylem of the bundle runs inward to form a central mass in the root. The stem, since it is exposed to the air, and the constant danger of the drying up of its cell sap by evaporation, is either covered by the same impervious epidermis and cuticle as the leaf, or has a still more effectual covering in the form of a special layer of cork. In the root evaporation is not a pressing danger, and the epidermis is hardly—sometimes not at all—distinguishable. The root branches into rootlets (Figs. VII. and VIII., Sh. VI.), and these, a little way behind their growing points, are covered by projecting thread-like cells—the root hairs.

SHEET II.

1. Epidermal cell from some parallel veined leaf showing stomata open. 1a., a stoma closed.
2. Epidermal cells from (e.g.) a cabbage. Notice how these cells interlock. g. e., guard cells of stoma. Note that the upper and under walls of these are thickened, and the internal wall (the one next to the stomatal passage) is thin. Increase in the amount of cell contents will separate the rigid upper and under walls of the guard cells, and straighten out the thin internal wall, so opening the central passage. Diminution of turgidity will result in the upper and under walls coming nearer together, and the flexible thin wall will bulge to close the aperture.
3. Lenticel. e. e., cork cambium. ep., epidermal cells, with e., cuticle. The loose cells are cork cells.
4. Transverse section of under side of leaf through a stoma. a. s., air space.
- 5 and 6. Figures to illustrate structure of secondary medullary rays. 6, is diagrammatic, the medullary rays, m. r., dark. The letters t. l., t., and r. l. correspond with the more realistic figures of 5, in which T. L. is a tangential section, T. a transverse, and R. L. a radial section of a stem to show these.
8. Diagrams of the process of nuclear division called Karyokinesis. 1, 2, 3, changes of the chromatin filament culminating in 4, the aster; 6, the diaster and the nuclear spindle; 7, appearance of the equatorial microsomata, mi., which coalesce to form the dividing cell wall.





These unicellular root hairs are intimately applied to the particles of soil, and osmose is continually going on between their contained cell sap and the thin film of water—hygroscopic water—which covers these particles even in the driest soil. Acid substances, of an excretory nature, pass out in small quantities from the relating dense cell sap; inorganic salts in weak solution, and therefore in large volume, pass in. In the case of insoluble substances (carbonate of lime for instance) the acid cell sap renders them soluble, or decomposes them, and gives rise to soluble compounds.

§ 19. Sheet III., with its accompanying text, summarises the chief movements of water and food material in an actual plant. The transpiration uprush has not yet been brought into agreement with mechanical or mechanico-biological theory. It probably passes up through the cavities of wood tracheides and vessels. The water, however, rises too high for mere capillarity, and too quickly to be the result of the excess of endosmose over exosmose at the roots. The endosmose from the roots, however, is probably the cause of what is called **root pressure** shown in the phenomenon called "*bleeding from the root stock.*" If a tree is cut down in summer, the cut surface of the wood of the stump dries by evaporation at first, but presently the sap rises again to the level of the cut and begins to ooze out from the xylem. Root pressure in spring, probably takes an important part in starting the transpiration current.

§ 20. A few simple experiments show the nature of transpiration: the withering of cut plants and their revival by immersion in water; the shrivelling of plants in dry soil on a hot, dry day, and their revival by conveying moisture to their roots; their failure to revive if the soil is protected from the moisture and the leaves wetted.* A bell jar may be put over a growing plant, and the air within, which may be dry at first, will presently become saturated, and directly a slight fall in temperature occurs, the glass will be bedewed internally. That the current

* E.g., by covering over the exposed earth of a flower pot all round the stem of a plant and then watering.

passes up through the xylem is shown by the proportion always observable between the amount of woody tissue and the extent of leaf (*i.e.*, transpiring) surface, by the reduction, and even absence, of xylem in a submerged stem, and by cutting through the centre of a branch down to the xylem all round without shrivelling the leaves, and the shrivelling that ensues as the xylem is cut into. Transpiration taking place, as it does, mainly or entirely through the stomata of the leaves, does not occur during the winter in trees that shed their leaves. For that reason they are usually transplanted when leafless, and in no danger of drying up. Transpiration occurs only in the daylight, so that "bedding out" is performed after sunset.

§ 21. It is necessary to explain how it is that **transpiration only goes on during daylight**. Attention has already been called to the stomata and to a figure showing a stoma in section. If the epidermis of a leaf that has been in the dark is peeled off (a cabbage leaf does very well), and examined with the high power of a student's microscope, it has the appearance shown in Fig. 1 *a*, Sh. II., *G.C.* *G.C.* are the guard cells of stomata; they lie close to one another and the stoma is closed. In Figs. 1 and 2 the condition of affairs in a leaf which has been for some time exposed to the light is seen. The guard cells, which, unlike most other epidermal cells, contain chlorophyll, have been assimilating; as a result of this, the soluble carbohydrate in them is increased, and this, by the well-known laws of osmose, leads to a diffusion of (*a*) a small quantity of carbohydrate out of the cell, (*b*) a larger quantity of water into it. The guard cells are distended, and, as a consequence of a peculiar distribution of thickening in their walls, assume a curved form on their inner edge and move away from each other. In this way it comes about that plants only transpire while they can assimilate.

§ 22. Cell sap, besides its fundamental importance as the vehicle of all transit in a plant, is supposed to be absolutely essential to growth at any particular point. The particles of a cell wall, for instance, are regarded as

being held apart by the cell sap that soaks them ; and *growth in the size of the cell* is effected by the intercalation of fresh particles (**Intussusception**) between the distended, or in botanical language *turgid*, substance. Without turgidity, that is, in a shrivelled condition, growth ceases. But growth of the cell wall, and especially *growth in thickness*, may occur by the direct addition of fresh matter at the surface (**Apposition**).

§ 23. We would call the attention of the student particularly to the enormous importance of water to the plant, and the great share taken by the simple laws of evaporation and osmose in the plant body. The great mass of a plant consists of water. It is a very simple but very instructive experiment to weigh a freshly picked plant and to weigh it again after drying in a hot oven. This is the great reason for the epidermis with its closely interlocking cells (*vide* Fig. II., Sh. II.) and gas-tight cuticle. Then the land-inhabiting plant uses water to bring up its food from the soil, and has to get rid of the excess of water. This necessitates the xylem of the vascular bundles and the stomata. Then water is the medium of transit of formed material, at least as regards carbohydrates. And finally, water lies at the base of all the organic compounds of the plant in combining with carbon in the leaves to form starch.

§ 24. After this brief *r  sum  * of the physiology of the flowering plant we shall be in a position to proceed to the study of some of the extreme variety of forms which different flowering plants have, under stress of varying conditions, assumed. Although it may not be the most logical, it will certainly be the most convenient way for our purpose to commence with the leaf, and proceed then to the stem and root. Our remarks will be illustrated by figures ; but we shall make constant reference, in addition, to familiar plants, especially to hedgerow, field, and garden forms ; and we would strongly advise the student to utilise his walks, and lose no opportunity in obtaining that more intimate acquaintanceship with vegetation which no text-book, however copiously it may be illustrated, can supply.

II.—*On the Structure of the Leaf.*

§ 25. We have already considered the microscopic section of the blade of a typical leaf, and noted its parts: (i) the cuticle, which prevents evaporation, with the stomata, regulating this process and the exchange of gases between the plant and air; (ii) the mesophyll, engaged in assimilation; and (iii) the veins, the xylem of which brings up the transpiration current with inorganic nutritive material from the roots, and the phloem of which probably conveys away formed proteids and carbohydrates.* We shall now consider the members of a typical *foliage leaf* (*i.e.*, a green leaf engaged in assimilation) as they appear to the naked eye, and the most obvious modifications of this typical structure that occur. We have (Fig. 1, Sh. IV.) a *blade* (*bl.*) placed upon a leaf stalk, the petiole (*pt.*). The lower part of the petiole may embrace the stem and form a sheath (*sh.*, Fig. 11), or it may have at its base blade-like expansions, the stipules (*st.*). When the petiole is absent, the leaf is said to be *sessile*. In the case of grasses, a single lozenge-like upgrowth occurs between the leaf-blade and the stem, called the *ligule*; the leaf is then spoken of as *ligulate* (Fig. 11). An *ochrea* is a kind of false sheath, formed by the confluent stipules in the dock, sorrel, and their allies (Fig. 12).

§ 26. The point at which the leaf is attached to the stem is called a *node*. The way in which leaves are arranged on a stem is called the *phyllotaxis*. Where there is one leaf at a node, the leaves are *alternate* (spiral), where two,

* We may note here, in extension of what has already been given, that in all leaves having a distinct upper or sunny, and under or shadowed, side, the stomata are largely absent from the former surface. But in leaves living in the shadow (as the fern) or inclined to the light, so as to be illuminated on both sides (as in the cabbage), the stomata occur on both sides, and the distinction of palisade and spongy parenchyma is not marked.

SHEET III.

SUMMARY OF PLANT PHYSIOLOGY.

1. Endosmose of water into root hairs, *r.h.*, with mineral salts in weak solution, including compounds of H, O, N, S, P, Na, K, Ca, Fe, Cl, Si, &c.

2. This water ascending by the xylem (probably through the cavities of the vessels) of the root (*r*),

3, stem (*st*),

4, and leaf veins, as the "erude sap." The major part of the water evaporates via the stomata, leaving the mineral salts in the plant sap to undergo synthesis.

5. Carbon dioxide entering the plant mainly, perhaps, through the stomata.

ASSIMILATION (S L=sunlight).

6. The oxygen released by assimilation leaving the plant.

7. Formed proteinaceous matter travelling via sieve tubes, and

8, formed carbohydrate (sugar) via *parenchyma*

9, to the growing point of stem, or

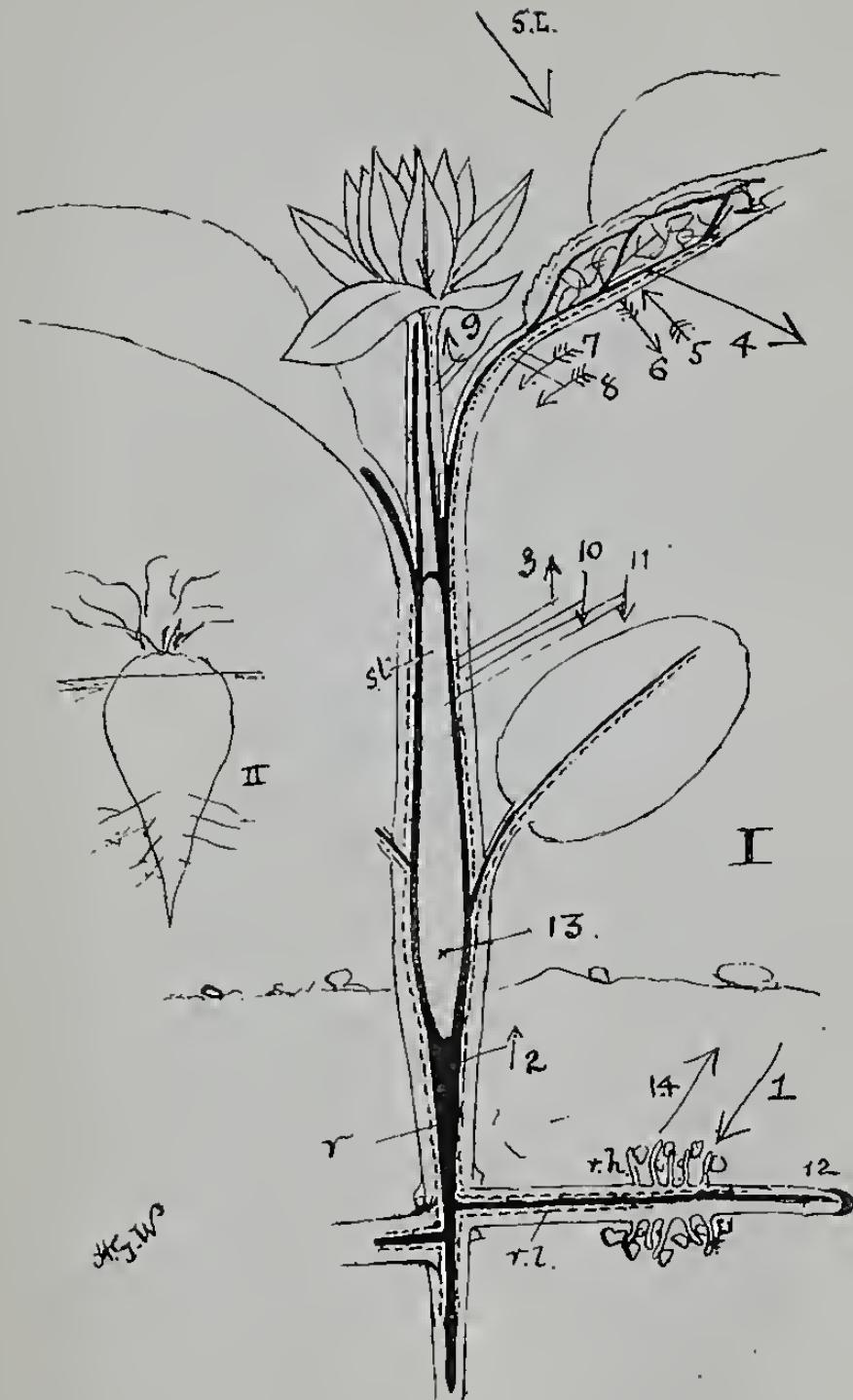
10 and 11, down the stem ("descending sap") to

12, growing point of root,

13, or to storage region in stem or root. (ep. Fig. 2. turnip store root.)

Kataboly must predominate at the growing points, and there probably the oxygen needed in *respiration* enters through the yet tender integument, and CO₂ may be exhaled.

14. Other Katastases perhaps escape at root by exosmose, or as odoriferous emanations, or remain in the plant as pigments and secretions.



opposite, where more than two, *verticillate* (= *whorled*). *Decussate* leaves are opposite leaves arranged with each pair in a plane at right angles to the next pair. Leaves springing from a short underground stem, or from the ground at the base of a stem, are often called *radical*, as in the daisy.

§ 27. When the blade of the leaf is divided right down to its principal vein into *leaflets*, separated from one another by intervals, the leaf is said to be **compound**. When the blade is not divided completely, the leaf is a **simple** leaf. Beginners occasionally experience a difficulty in distinguishing compound leaves from stems bearing simple leaves. They should bear in mind that a leaf from the time when it begins to unfold from the bud is complete to its apex, while a stem terminates in a bud, *i.e.*, in a growing point. No ordinary leaf bears buds. This distinction explains why the so-called leaves of the butcher's broom (Fig. I., Sh. IX.) are regarded by botanists as stem structures. Although they outwardly resemble leaves in the closest manner, they normally develop flower buds and flowers upon their surfaces.

§ 28. Compound leaves may either have their leaflets arranged along a main stem or *rachis*, as in the mountain ash or acacia (*pinnate compound leaves*, Fig. 2, Sh. IV.), or radiating from one point, as in the horse chestnut (*palmate*, Fig. 3). Pinnate leaves with an even number of leaflets are called *paripinnate*; with an odd number, *imparipinnate*. Palmate leaves with three leaflets are called *ternate* (clover). Where a pinnate leaf has its leaflets compound again, the term *bipinnate* (Fig. 13) is used; where the leaflets are of a still higher order, *tripinnate*, and so on. Similarly we have *biternate* (Fig. 14), *triternate*, etc. The leaves of the orange are peculiar. They are compound leaves with one leaflet, which at first will strike the reader as an absurd contradiction in terms. But the leaflet is distinctly jointed on to the abbreviated rachis, and there is little doubt that this leaf is a compound leaf of which the number of leaflets has been reduced to one (Fig. 15).

§ 29. The **Venation**, that is to say, the way in which the fibro-vascular bundles are arranged in the leaf, is of considerable importance from the point of view of systematic botany. In British ferns the veins fork and fork again, and the branches do not reunite. This is called *furcate* venation. In flowering plants the veins are either arranged in a complex network or the inter-communications are parallel. The former is *Reticulate Venation*, and is characteristic of that one of the two great divisions of the true flowering plants, called the Dicotyledons. The latter is *Parallel Venation*, and distinguishes most of the second division, the Monocotyledons (blade of grass, lily of valley, tulip). When leaves of either of these divisions have long blades, there is commonly a marked main rib or *midrib* running up the centre, and the venation is *pinnate* (rose, beech, oak); but where the leaves are broad, the midrib is abbreviated, and the chief ribs radiate from one point like the fingers of an outspread hand; in which case the venation is *palmate* (ivy, vine).

§ 30. Certain terms indicative of the general form of a leaf or leaflet may be given here. A spiny erect form is *acicular* (16), a flexible line *linear* (17). *Lanceolate* (18), *oblong* (19), *ovate* (= egg-shaped, 20), *obovate* (the former reversed, 21), *spatulate* (22), *oval* (23), *round* (24), *cordate* (heart-shaped, 25), *obcordate* (26), and *reniform* (27), are best illustrated by figures. A leaf (or leaflet) with pinnate venation may be cut into, towards its midrib, to a third or more of the distance (*pinnati-fid*, 28), half-way or more (*pinnati-partite*, 29), or practically the whole way (*pinnati-sect*, 30). The next step would be a compound leaf. Similarly we have *palmati-fid*, -*sect*, and -*partite* (31 and 32). When the margin of the leaf or leaflet is a smooth unbroken line, we have an "*entire*" margin (4). When a series of slight marginal incisions render the margin toothed like a saw, we have a *serrate* margin (5); *biserrate* is when the serrations are again serrate (6); *crenate* (7) and *dentate* (8) are figured. *Bidentatae* indicates that the dentations are again dentate. *Sinuate* indicates a wavy margin (9), and *lucinate* (10) an irregularly jagged one. The tip or *apex* of the leaf is also usually

noticed in description. It may be *rounded*, *acute* (*i.e.*, an acute angle), *obtuse*, *acuminate*, *truncate*, or *retuse* (33 to 37).

§ 31. Beside the forms of leaf covered by the above terminology, we may note the *peltate* leaf, where the petiole is attached to the blade, not at its margin, but from the under side, as in the common garden flower known popularly as the nasturtium, in the canary creeper, or in the water lily (Fig. 38). Many submerged aquatic leaves are greatly subdivided, and are said to be *dissected* (water crowfoot). Almost all leaves have a distinct upper and under surface, and are called *bifacial*; but some (as the stonecrop) have round leaves with no such distinction. These are styled *centric* leaves. In some cases the blade may be absent, and the flattened petiole may take its place functionally and in appearance, in which case it is spoken of as a *phyllode* (*mimosa*). The pitcher plant traps insects by means of pitcher-shaped leaf blades. Connate leaves (as in the honeysuckle) are opposite leaves which are confluent at their bases.

§ 32. Many foliage leaves add to their typical functions by taking on secondary duties. Thus the petiole of the canary creeper leaf twines round supports and serves for climbing (*petiole tendril*); the end of the midrib of the compound leaf of the pea undergoes a like modification (*blade tendril*), while the stipules of the melon or bryony answer the same purpose (*stipule tendril*). In the yellow furze of our commons the whole leaf becomes a thorn, while in the garden acacia (*Robinia pseudacacia*) the stipules form *stipule thorns*.

§ 33. All the above forms of leaves agree, however, in being green and in discharging the function of assimilation, and they are all classed together as **Foliage Leaves**. But besides there are two other groups of leaves, the **Scale Leaves** and the **Floral Leaves**, which do not assimilate, or assimilate very little, and which have taken on other functions. They are regarded as *modified* from the

original foliage form. **Scale Leaves** (=Cataphyllary Leaves) are usually simple and attached by a broad base to the stem. They may be brown and dry, as in the case of the protecting scales outside winter buds (*vide* horse chestnut in spring); or they may be fleshy and full of stored material, as in the hyacinth bulb. The first leaves formed in the seeds of all flowering plants and of the pine are called the *Cotyledons*. In the pine there are several of these, greenish, and not unlike the rest of the foliage; but in most of the true flowering plants the cotyledons often differ in form and general character from the other leaves of the plant. In the flowering plants there are either one or two of these primary seed leaves, and it is this that supplies the primary distinction between the two great divisions of Monocotyledons (with one) and Dicotyledons (with two). We may perhaps give here a description of four typical seeds, to illustrate more clearly this matter of the cotyledons.

§ 34. If the student will obtain a pea (a bean will do just as well) and strip off the coat (the *testa*), he will find the contained portion splits readily into two hemispheres (Fig. XI., Sh. XI.). These are the *cotyledons*, which, like the scale leaves of the onion bulb, are enormously gorged with food material. At one point they are in contact, and there is a blunt process, the *radicle*, the future root, and a curved feathery *plumule*, or embryonic stem, lying between the cotyledons. Plumule, radicle, and cotyledons are together spoken of as the embryo. At *germination*, that is, when the seed begins to develop in spring, the root first commences to develop, and grows downward into the soil, sending out root hairs and absorbing water. The cotyledons then separate, and the plumule pushes its way up and opens its leaves out to the light. The growth of the young plant is at first at the expense of the stored material in the cotyledons, and they become shrivelled up by the time it has begun to assimilate with the leaves. The Barcelona nut or the hazel (figured) can similarly be split into two cotyledons; but the plumule, pointing away from the sharp end, is shaped like a candle flame and in a direct line with the radicle.

SHEET IV.

GENERAL FORMS OF LEAF.

1. Simple leaf. *bl.*, blade. *p.*, petiole. *st.*, stipules.

Compound Leaf: 2. Impari-pinnate. 3. palmate.

Margins: 4. Entire. 5. serrate. 6. biserrate. 7. crenate. 8. dentate.
9. sinuate. 10. lacinate.

11. Amplexicaul (=sheathing) leaf of grass with ligule, *lig.*;
sh., sheath.

12. Ochreate leaf.

13. Bipinnate leaf.

14. Bitemate leaf.

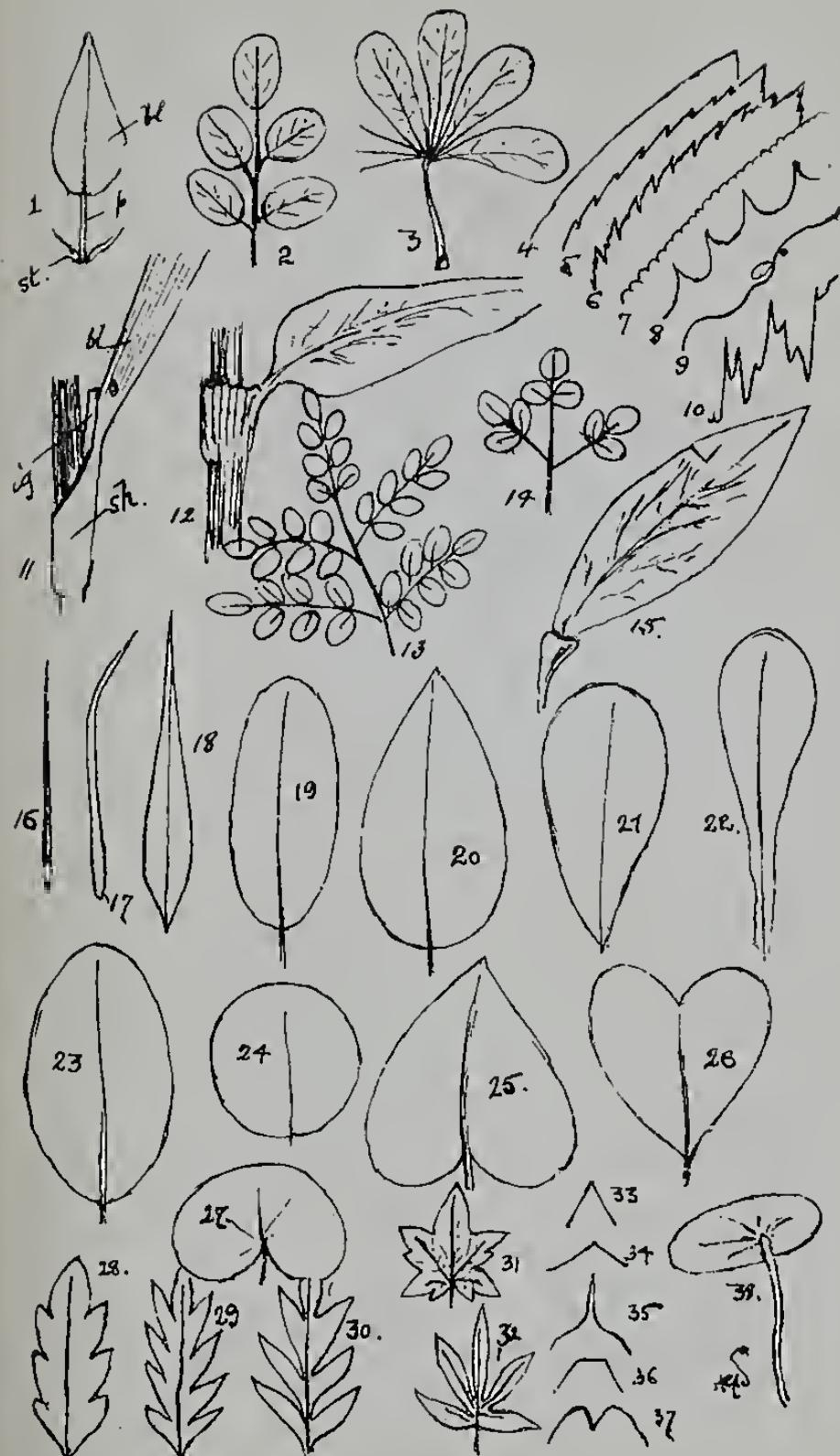
15. Peculiar reduced compound leaf of orange with one leaflet,
which it will be noticed articulates with the rachis.

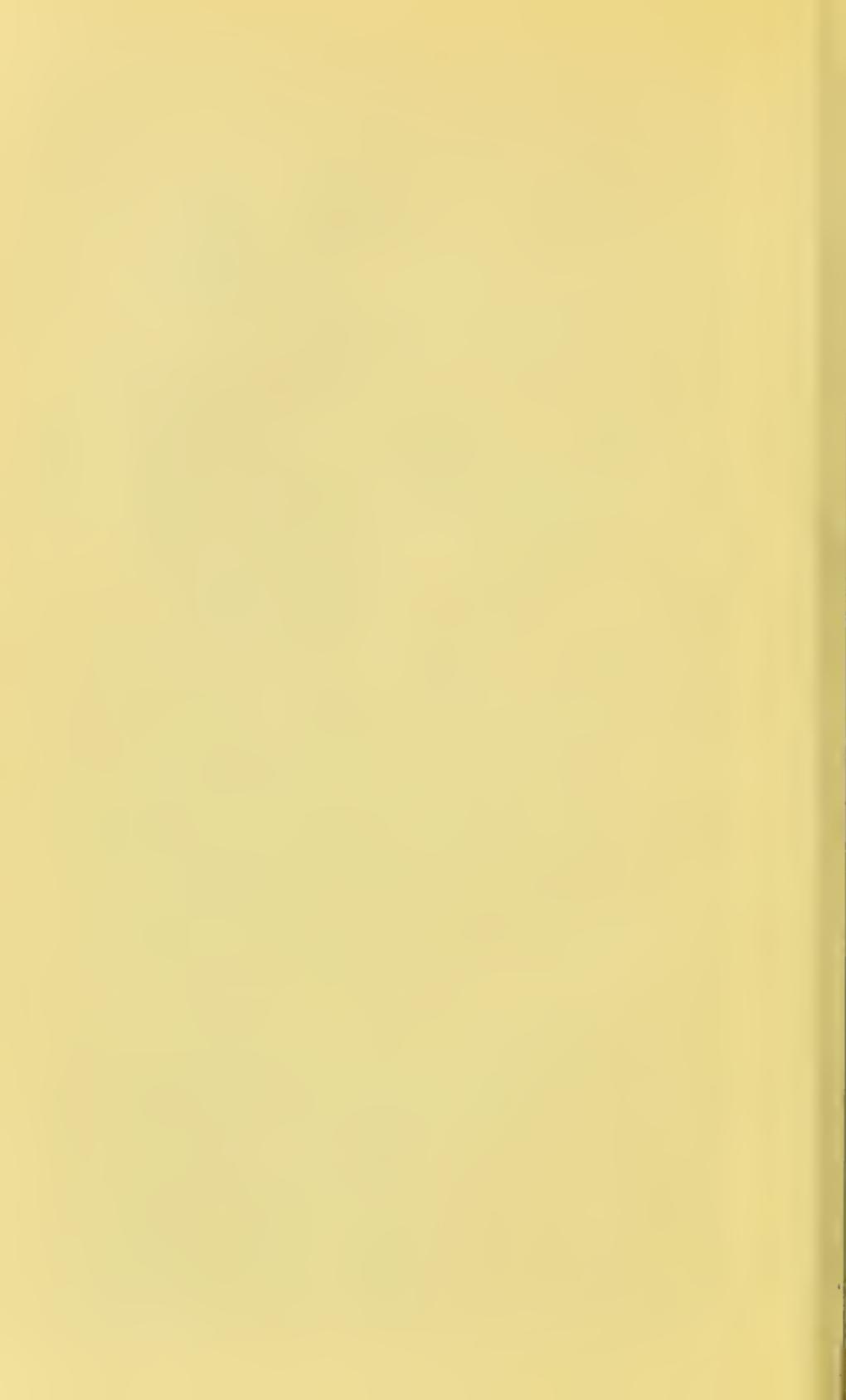
Terms used in describing leaves (and sepals, petals, etc., also):

16. *Acicular* (stiff, erect). 17. *linear* (flexible). 18. *lanceolate*
19. *Oblong*. 20. *ovate* (egg-shape). 21. *obovate* (=20 reversed).
22. *spatulate*. 23. *elliptical*. 24. *round*. 24. *cordate*. 26. *ob-*
cordate. 27. *reniform*. 28. *pinnatifid*. 29. *-partite*. 30. *-sect*.
31. *palmati-partite*. 32. *-sect*.

Terms used for apex of leaf, petal, sepal, &c.:

33. *Acute*. 34. *obtuse*. 35. *acuminate*. 36. *truncate*. 37. *retuse*.
38. Peltate round leaf of the garden Nasturtium (=Tropaeolum).





§ 35. If the very much smaller seed of a buttercup or of a poppy (Fig. 1, Sh. XI.) be now examined, the interior of the testa is found to be occupied with a mass of store material, the *albumen*, or *endosperm*. The embryo is very small, and lies embedded in this at one end of the seed. A radicle and two cotyledons can be made out in it, but these latter are small, and no plumule can be distinguished until germination begins. Such a seed as this, with a small embryo embedded in the endosperm, is said to be an **albuminous seed**. In the pea the embryo has consumed all the endosperm, and its cotyledons are gorged therewith. It has no albumen outside the embryo, and is spoken of as **ex-albuminous seed**.

§ 36. Both poppy and pea are evidently Dicotyledons. For the purpose of comparison the seed of the date (*i.e.*, the date stone) may be taken as a typical Monocotyledon. This also is albuminous; the whole embryo is very small, and radicle, plumule, and cotyledon can scarcely be distinguished until germination begins (see Fig. XII., 1, 2, 3, 4, Sh. XI.). The embryo is larger in the maize (Indian corn, Fig. X.), and its parts may be distinguished. There is a sheath over the radicle (*r.sh.*), and a large expansion pressed against the endosperm is called the *scutellum* (*sc.*), and in this case does the work of the usual single cotyledon,* since it is very obviously a sucker to absorb the endosperm when the plant is germinating. In the case of the pea, where the cotyledons actually contain the stored material, they always remain below ground, and are called *hypogea*. Evidently hypogea cotyledons are "scale leaves." In the sunflower the cotyledons push their way to the surface, become green and assimilate, and are altogether, except in shape, like the ordinary foliage leaves. They are therefore styled *epigeal*.

§ 37. The parts of the flower and inflorescence, the petals, sepals, stamens, carpels, and bracts, to be described later,

* It is doubtful whether the scutellum is really the cotyledon or a special outgrowth beneath it.

are all regarded as modified leaves. This view is strengthened by the evident identity of bracts and sepals with leaves, by the occasional conversion of some of these organs into others (stamens into petals, for instance, in double flowers), and by the unbroken gradation of leaf-like sepals into white petals and petals into stamens in such a flower as the water lily. In the double cherry in the place of carpels a cluster of small green leaves sometimes appears. These floral parts therefore may be spoken of collectively as the **Floral Leaves**. We shall deal with them more fully in the chapter we shall devote to the flower.

III.—*The Stem.*

§ 38. The leaf is the most essential part, physiologically speaking, of the plant above ground. The chief function of the typical stem is to raise the leaves towards the light, to separate the nodes* so that the leaves do not overshadow one another, and to bring up absorbed material from the roots. It is therefore commonly erect, or ascends obliquely. If green and lasting but one year, as in the sunflower or grass stem, it is *herbaceous*; if a tree or shrub continuing to grow for many years, woody. *Perennial* is a rather wider term than woody, including as it does plants having underground stems lasting several years. But it may, instead of rising by its own strength, avail itself of the work of more energetic plants and climb over them. It may either climb by leaf tendrils, as in the cases already noticed, or by itself actually coiling round supports (twining stem, as in convolvulus), or by developing a special sort of clinging stem structures (stem tendrils, as in the vine). In certain cases it may become modified in order to secure the spreading of the plant. The *runner*, for instance, is a stem which creeps over the surface of the ground and sends down roots from each node as well as leaves above. The strawberry is a good instance of this. The stem may also become a region of storage, and then it is not infrequently buried with its treasure underground. The *rhizome* (as in the bracken fern) is such a stem. The *corm* (crocus) differs from the rhizome in being short and erect, while the rhizome is elongated and spreads horizontally through the soil. The *tuber* (potato) is short and fleshy, and not erect. These underground stems are to be distinguished from roots by the facts (i) that they bear leaves (scales, *i.e.*) and buds, which no root does; and (ii) they have no root cap, such as is invariably found protecting the growing point of a root (*vide infra*, § 53). The cactus

* Intervals of stem between the nodes are called the internodes.

is a peculiar erect *fleshy* stem, which lives normally in arid regions, and by means of an extremely thick cuticle is able to store water. *Spines* (as in the sloe) are short, specially hardened branch stems, which subserve a defensive purpose. The branch stems of the butcher's broom at first sight resemble leaves in form, and perform all the functions of a foliage leaf (see § 30). Such leaf-like stems are called *cladodes*. The essential difference of leaf and stem is the termination of the latter in a growing point, and its capacity for producing latent buds.

§ 39. The *bulb* (tulip, onion) is something more than a modified stem. It is a short stem bearing scale leaves, or more strictly a bud, and either the entire leaves or their bases are inflated with store material.

§ 40. A bud is a young branch stem, the internodes of which are not developed, and in which, consequently, the future leaves are crowded together. The outer leaves of *winter* buds may be scaly, hairy, resinous, or otherwise protective. Almost invariably in flowering plants the buds appear in the *axils* of leaves, that is, in the angle between leaf and stem. It is pleasant, as well as instructive, in spring to watch the winter buds day by day burst off their non-conducting protective scales, and to notice how the young shoots elongate and the leaves unfold.

§ 41. We may now proceed to consider the histology of the stem. The stem, like the leaf, is usually exposed to the air and to the dangers of drying up by evaporation, and, like the leaf, it is always covered by a distinct *epidermis*, or else by a still more effectual water-tight or gas-tight layer, the *cork*. Within this is a cylinder of *parenchyma*, the *fundamental tissue*, and through this run the *vascular bundles*.

§ 42. The *vascular bundles* consist of *phloem* and *xylem*, as we have already stated. The mutual arrangement of these two elements and the distribution of the bundles in the stem vary considerably, and the chief varieties follow

the chief divisions of the higher plants. We may very conveniently give a systematic scheme of the vegetable kingdom based on these distinctions here.

A. Cellular Plants have no vascular bundles.

THALLOPHYTA (e.g., *Spirogyra*, *Saccharomyces*, *Vaucheria*, *Fucus*, *Chara*, *Mucor*, *Penicillium*).
MOSES and LIVERWORTS.

B. Vascular Plants have vascular bundles.

1. VASCULAR CRYPTOGAMS, as the fern, have the phloem in each bundle completely surrounded by the xylem. This type of bundle is called the *concentric* (Fig. 4, Sh. XIII.).
2. PHANEROGAMS have the phloem and xylem on the same radius of the cross section of the plant, the xylem internal to the phloem. This type of arrangement is called *collateral*. In *Gymnosperms* (e.g., the pine) and *Dicotyledons* the bundles are commonly arranged in a single ring; in *Monocotyledons* they are scattered, apparently haphazard, through the stem (Sh. V.).

§ 43. We may perhaps describe types of each of these latter. Fig. I., Sh. V., represents a vascular bundle of the maize, a particularly well-developed *Monocotyledon* in transverse section and under the high power. The xylem here is V-shaped, and the phloem lies between the arms of the V. Almost invariably we have laterally two dotted vessels, and in the median line a spiral and an annular vessel, and a schizogenous air space as we approach the apex of the V. The whole of this little bundle is surrounded by a peculiar thickened parenchyma belonging to the ground tissue, and called sclerenchyma. Immediately under the epidermis of the maize is a continuous layer of such sclerenchyma not connected with any bundles.

§ 44. In Fig. III. a young stem of the sunflower is seen in transverse section. Here we have the arrangement characteristic of the *Dicotyledons*. In addition to the two

elements, phloem and xylem, present in the vascular bundles of a monocotyledon or a fern, we find in the dicotyledons and gymnosperms a third, the **cambium**, between these two. The cambium is always meristematic tissue, and continues to divide throughout the life of the stem. It gives off cells internally, which become wood vessels or xylem, prosenchyma or parenchyma, while externally it adds similarly to the phloem. Hence the dicotyledon bundle is always growing. It is spoken of as an **open bundle**. In contradistinction the bundle of the maize, which when once formed *has no cambium* to continue its development, is called a *closed bundle*. Examined in detail (Fig. I., Sh. VI.), the sunflower stem in transverse section or longitudinal section shows, if the section pass through a bundle, the following series of cells proceeding from without inward.

Epidermis, a *single layer* of cells with the outer walls cuticularised, water- and gas-tight, and preventing evaporation (*ep.*). Stomata at intervals regulate transpiration.

The Cortex—

Collenchyma, several layers of chlorophyll containing cells with walls especially thickened at the corners (*col.*).

Layers of large parenchyma.

A single layer of cells, the *Bundle Sheath*.

The Vascular Bundles, consisting of—

THE PHLOEM.

Patches of greatly thickened prosenchyma (*sclerenchyma*), the bast fibres.*

Soft bast or phloem proper. Sieve tubes and parenchyma.

THE CAMBIUM, consisting of meristematic cells flattened radially (*cp.* Fig. VII., Sh. V.).

THE XYLEM of—

Vessels.

Prosenchyma.

* Where this constituent is absent the bundle is called not a fibro-vascular but a vascular bundle.

Finally, internal to the ring of vascular bundles comes the very extensive **Pith** of large parenchymatous cells.

§ 45. The spaces between the separate bundles of the young sunflower stem are called **primary medullary rays** (Fig. VIII., Sh. V.). They must not be confused with the secondary medullary rays to be presently described. The bundles run straight in a cylinder from node to node in this stem. At each node bundles from the leaf enter the stem (leaf trace), and the bundles branch to form a zigzag ring at the node. So that the primary medullary rays have the vertical measure of the internodes.

§ 46. An old stem of the sunflower presents a somewhat more complicated structure (Fig. IV., Sh. V.). Across the primary medullary rays meristematic tissue has extended from the cambium of one bundle to the cambium of the next, so as to largely obliterate these and form a complete ring of cambium round the stem. The part of this ring which belonged to the original bundles is called *intrafascicular cambium*; that which has bridged the interval, *interfascicular*. All round the stem the cambium may give off fresh xylem elements internally and phloem externally. So that we have in this older stem—

- (a) *Epidermis*.
- (b) *Cortex* (constituents as above).
- (c) The original phloem of the separate bundles (*Primary Phloem*).
- (d) A complete ring of phloem (*Secondary Phloem*).
- (e) *Cambium*.
- (f) A complete ring of xylem (*Secondary Xylem*).
- (g) The original xylem of the separate bundles (*Primary Xylem or Medullary Sheath*).
- (h) *The Pith*.

§ 47. The rings of secondary xylem in the sunflower never attain any great thickness, as the life of the stem begins and ends in a summer. But in **woody stems** (Fig. V., Sh. III.), which last many years, the secondary xylem increases to an enormous extent and forms the great mass

of the tree. It is then marked by concentric zones, the *annual rings* (each representing a year's growth), the ringing being due to the relatively small size and thick walls of the wood cells found in autumn, which makes the autumn wood appear dark. The cavities of the wood cells formed in spring, when transpiration is active, are larger and their walls thinner. Extending from the cortex towards the pith, through the wood are found ribbons of parenchymatous cells, one or two cells wide and six or seven high. These are the secondary medullary rays, and they form a medium of osmotic communication between the parenchyma of pith and cortex. They are figured fully (Figs. V. and VI., Sh. II.). Recently formed wood is called *alburnum*, and is the active tissue; the *duramen*, the older xylem towards the centre of the tree stem, does not participate in the transpiration current.*

§ 48. As the woody stem increases in thickness, a continually increasing strain is put upon the epidermis, and at last it ruptures. The cortex would then be exposed to the danger of destruction by the evaporation of all its moisture were it not for the appearance of **cork**. A ring of cells in the cortex becomes meristematic, and constitutes what is called the **cork cambium** or *phellogen*. (Cells which reassume active division after a comparatively quiescent interval are spoken of as secondary meristem, in distinction from the primary meristem of the growing point.) This gives rise externally to layers of the brick-shaped impermeable cork cells. When there are layers of chlorophyllaceous cortex formed internal to this, they are spoken of as *phelloiderm*. The phellogen may arise just beneath the epidermis,† as in the *poplar*; or at any depth in the cortex, or even in the phloem, as in the vine. Typically on woody stems succes-

* In many text-books the statement is still found that the transpiration water does not ascend through the cavities of the vessels, but through the thickness of the walls. Recent work, however, seems to show that the current really does ascend, as the student would naturally expect, through the cavities, not perhaps as a continuous stream of water, but rather in the form of a succession of bubble films.

† The phellogen of the willow is derived from the dermatogen.

SHEET V.

1. (a) Transverse and (b) longitudinal section of a fibrovascular bundle of a Monocotyledon (Maize). *Ph.*, phloem. *s. t.*, sieve tubes. *pr.*, lignified parenchyma surrounding bundle. *an. v.*, *s. v.*, and *p. v.*, annular, spiral, and pitted vessels of the xylem, at the apex of which is an air space, *a. sp.*

2. Diagram of bundle arrangement of a monocotyledon—most English monocotyledons have less completely developed bundles than the maize. Where monocotyledons become trees they often thicken the stem considerably by the development of masses and rings of sclerenchyma (hard prosenchyma), in the fundamental tissue beneath the epidermis. More or less of this occurs in most monocotyledons.

3. Arrangement of fibrovascular bundles in a young dicotyledon (Sunflower in early summer, e.g.). P. M. R. primary medullary ray. *Camb.*, fascicular cambium. *Co.*, cortex *Ep.*, epidermis. Compare 8.

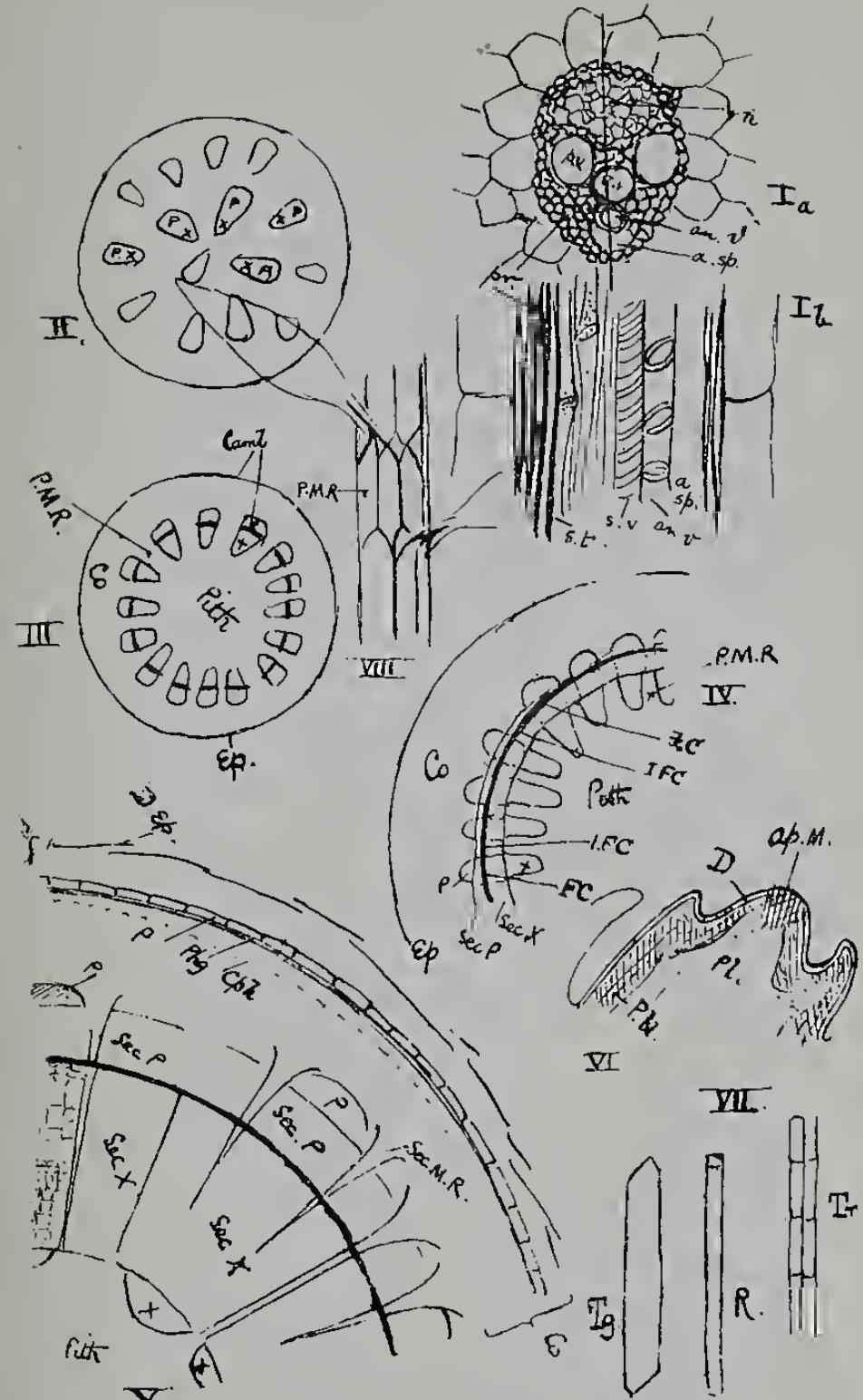
4. Commencement of secondary thickening of a dicotyledon stem (Sunflower main stem in September, e.g.). F. C. the fascicular, and I. F. C. the interfascicular cambium have formed a complete ring. X. is the primary xylem, P. the primary phloem, sec. X. secondary xylem, sec. P. secondary phloem, ep. epidermis, co., cortex.

5. Section of such a woody stem as may be got by cutting any young twig of a tree. The secondary xylem would show one or two annual rings. The primary medullary rays are best regarded as obliterated. Sec. M. R. are secondary medullary rays, of which those that reach the pith must be relics of the primary medullary rays. The cortex has developed a secondary meristem, *Phg.*, the phellogen, which forms periderm (P.) or cork externally, and may, in addition, give rise to chlorophyllaceous cells, the phelloiderm (eph.) within. The cortex external to the cork, with D. Ep., the decaying epidermis form *B.*, the bark.

6. Growing point of phanerogam stem. *Ap. M.*, the apical meristem, dividing off cells, which are presently seen to belong to three series; *D.*, the dermatogen forming the epidermis, never dividing tangentially but always one cell thick; *Pbl.*, the periblem, and *Pl.*, the plerome, giving rise to the vascular cylinder. The bundles appear in this as strands of cells, the *pro cambium*, which differentiate.

7. Cambium cell tangential (Tg.), Radial (R.), and transverse (Tr.) views.

8. Stem of dicotyledon as a transparent object to show arrangement of bundles.



sive phellogens appear, superseding each other year after year deeper and deeper in the stem. Wherever the cork appears, however, it cuts off all the tissues external to it from nutrition and the general life of the plant, since it is water-tight. The parts so cut off die and dry up, and the brown layers of disintegrating cells thus formed constitute the bark.

§ 49. The structure of the growing point of the stem of a flowering plant will be understood from Fig. VI., Sh. V. It is overshadowed by young leaves, which form, together with it, the terminal bud of the stem. There is in the flowering plant no single terminal growing-point cell, the *apical cell*, as there is in ferns, from which all other cells are derived. Instead there is a mass of cells, the *apical meristem*. A little way below this three concentric layers are apparent. The outermost *never divides by division planes parallel to the surface*—never, that is, becomes more than one cell thick—and it gives rise to the epidermis. This is the *dermatogen*. Internal to this is the *periblem*, which forms the cortex, and internal to that again the *pleurome*, the cells of which ultimately differentiate to form the vascular cylinder.

§ 50. Branching occurs in one of two ways. In Vascular Cryptogams the apical cell frequently simply divides into two, and each half becomes the growing point of a new shoot. The two resultant shoots are here of equal value, and the branching is **dichotomous**. But in Phanerogams a subsidiary growing point appears at the side of the chief one, and gives rise to a branch; in other words, the branching is not terminal, but *lateral*, and it is called **monopodial**. The two varieties of monopodial branching, cymose and racemose, need not be considered until the section concerning the inflorescence is reached.

IV.—*The Root.*

§ 51. We have already stated that the primary functions of the root are fixation and the absorption of food. We have also called attention to its excretory function. We have, moreover, specified two important differences from the stem : (1) the central position of its vascular cylinder ; (2) its feebly marked epidermis. To these distinctions we may add three others. A root (3) never bears leaves, either foliage leaves, floral leaves, or scales. It follows that it bears no buds. By this we recognise the potato, with its "eyes," or buds, as a stem. Moreover (4), when a stem branches, its epidermis and its cortex are continuous with those of the branch ; but the branch of a root springs from the layer beneath the cortex (*pericambium*), and it ruptures the cortex to emerge (*cp. Fig. V., Sh. VI.*).* The stem is said therefore to branch *exogenously*, the root *endogenously*. Finally (5), the growing point of the root (Fig. VI.) has no very distinct *dermatogen*, and is protected by a **root cap**, formed by a special layer, the *calyptrogen*.

§ 52. In Dicotyledons and Gymnosperms the radicle of the embryo (§ 34) becomes the main root of the plant, and is called the primary, normal, or **tap root**. In the Monocotyledons the radicle never emerges from the seed, and the numerous roots grow out from the base of the stem. Roots not connected with the original radicle, but growing from stems or leaves, are called *adventitious roots*. The ivy climbs by such roots, and the "runner" of the strawberry develops them at every node.

§ 53. The comparative security of the root buried in the soil renders it a frequent seat of storage in the plant (*e.g.*, *dahlia*). In many biennials (turnip, *e.g.*), which store food

* Root branches arise from the bundle sheath (*endodermis*) in ferns.

in the first year of their lives, and flower, form seed, and perish in the second, the root becomes enormously inflated.

§ 54. Coming now to the more detailed study of the root, we may again call the attention of the student to the relatively large size of the cortex as compared with that of the stem, and the reduction of the pith. In the young root of a dicotyledon, instead of the xylem and phloem being arranged the one internal to the other, they alternate in a single ring (Fig. III., Sh. VI.). There may be two, three, or four bundles thus arranged. The cambium passes in and out between xylem and phloem. External to this is a ring of meristematic tissue, the *pericambium*, from which the branch roots arise. Then comes a bundle sheath. Without this is the mass of the cortex, having externally the indistinct epidermis and root hairs. The cambium forms fresh (secondary) xylem internally and (secondary) phloem externally, as in the stem, and gradually becomes more circular as the root grows older. The secondary xylem is formed on radii alternating with the primary xylem. The *pericambium*, as development proceeds, gives rise to the phellogen, instead of this being derived from the cortex. The whole of the external cortex is thus cut off, and dies (Fig. IV.).

§ 55. In a monocotyledon root there is no cambium, and no cork ever cuts off the cortex from the vascular cylinder. The number of phloems and xylems is usually more numerous than in the Dicotyledons (six, seven, or more).

Note on Trichomes.

§ 56. **Trichomes** (hairs) are epidermal outgrowths. They may either be unicellular outgrowths of epidermal cells (unicellular hairs) or multicellular. Hairs have commonly a protective function; closely set over a leaf, for instance, they prevent water, by its surface tension, from coming into contact with the surface of the leaf; and when forming a woolly covering over buds, they check the loss of heat in winter. They also subserve the special need of many seeds, rendering them light and easily dispersed by wind. The fruits of the dandelion or thistle have a crown of hairs, the *pappus*, to the same end. The hairs of the stinging nettle have a sharp point, below which is a drop of irritant poison. Root hairs are trichomes. An *emergence* is a projecting mass of epidermal cells, but in addition *with a core derived from the cortex*. The *prickles* of the rose are such emergences. They break off easily from the stem, and the epidermis only is ruptured. The spines of the sloe, on the other hand, are really branches, and to break them off the shoot must be wounded to its xylem.

SHEET VI.

1. Transverse and (2) longitudinal sections of a Sunflower stem.
Vide Text, § 44, and compare sheet 5, fig. 3.

3. Very young root of a dicotyledon (cut for this, radicle of a germinating seed). *Pr. X.*, primary xylem. *Camb.*, the cambium. *P.*, the primary phloem. *Peri.*, pericambium. *Endo.*, endodermis, inner layer of cortex. *Co.*, cortex, of which the outer layer is sometimes called ectodermis; *ep.*, the INDISTINCT epidermis; *r. h.*, root hairs.

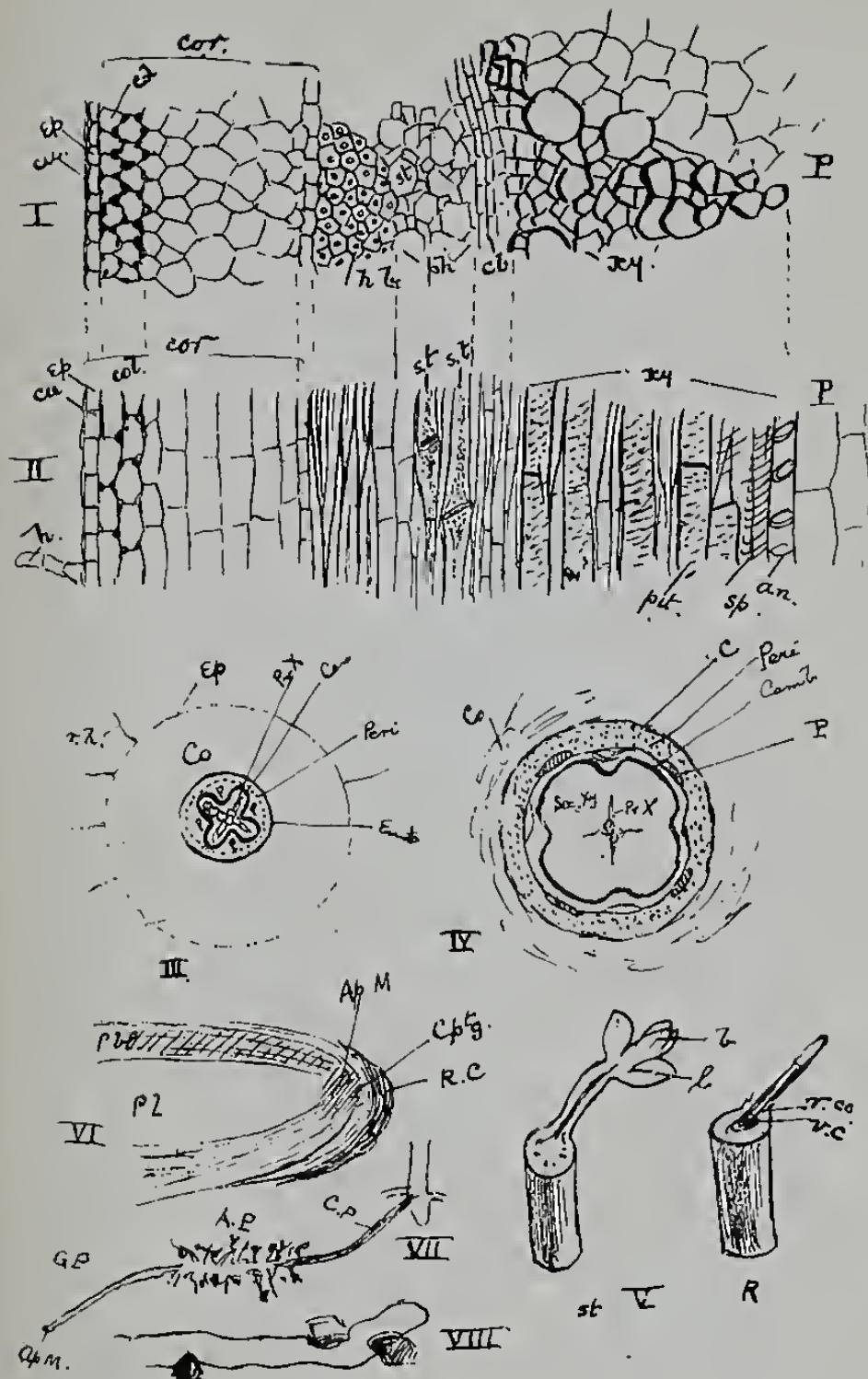
4. An older root, letters as before, but notice in addition, *Sev. xy.*, the secondary xylem, and outside the cambium the secondary phloem. The Pericambium has divided actively to form several layers of cells, the secondary cortex, the outermost of which are corky (*C.*) and cut off the ruptured and disintegrating primary cortex *co.*

5. Difference of stem and root. See § 51.

6. Growing point of root. Compare sheet 5, fig. 6. Note the absence of a dermatogen and presence of a calyptrogen, *cptg.*, forming a root cap, *R.C.*

7. Rootlet. *G.P.*, growing part. *A.P.*, assimilating part with root hairs. *C.P.*, conducting part, which has lost the hairs.

8. Root hair and particles of soil.





Conditions Affecting Growth.

§ 57. Turgidity is essential (§ 21).

§ 58. Temperature affects growth. The maximum temperature under which a plant can live is about 50° C.; the minimum, zero. For each plant there is a most favourable temperature, or *optimum*, and this may be, as a rule, the mean temperature of the climate in which the plant naturally occurs.

§ 59. Bright light appears to retard growth in most instances, though a fair amount of light is of course indirectly necessary for growth, since it is essential to nutrition; so that the shoots of "etiolated" plants, that is, plants grown in the dark, are commonly longer and slenderer than they would be under normal circumstances. The shaded side of an ordinary stem therefore grows more strongly than does the illuminated side, and the stem bends towards the light (sunflower, *e.g.*). This law does not hold universally. The ivy stem bends away from the light. Stems which bend sunward, as do most stems, are said to be *positively heliotropic*; stems which follow the ivy are *negatively heliotropic*.

§ 60. The direction of growth is largely determined by gravitation. Roots commonly grow towards the centre of the earth; stems, typically, away from it. These two tendencies are spoken of as *positive* and *negative geotropism*. By fastening germinating seeds to the rim of a continually rotating wheel, the action of the earth's gravitation on them can be eliminated. The stems will then grow centrifugally; the roots centripetally.

Questions on the Physiology of the Flowering Plant.

1. How does the nutrition of an animal differ from that of a plant, in respect of (1) the substances assimilated, (2) the mode in which they are assimilated ?
2. How does the chemical nature of the food required respectively by animals, green plants, and colourless plants differ ?
3. (a) Name the chief Carbohydrates found in plants.
(b) Describe briefly—
 - (i) The form of occurrence of each.
 - (ii) The probable use in the economy of the plant of each.
 - (iii) The reactions by which each may be recognised.
4. What is meant by Transpiration ? Describe simple experiments by which its occurrence and nature may be demonstrated.
5. State what are the conditions which are essential to the formation of starch in chlorophyll corpuscles. Describe the structure of a chlorophyll corpuscle.
6. Write an account of the functions performed by the epidermal tissue.
7. Represent in a sketch, and name carefully, the following tissues, as seen in the transverse section of a leaf of a typical Dicotyledon :—
 - (i) Epidermis, with cuticle and stomata ;
 - (ii) Mesophyll ;
 - (iii) Vascular bundles ;and assign to each its primary function.
8. How, and in what organs, would you demonstrate the origin of starch granules, and their re-formation in the reservoirs of reserve materials ? In what form, and through what channels, does the transfer from the place of origin to that of re-formation take place ?
9. (a) What is meant by assimilation in plants ?
(b) What conditions are necessary for the process to go on ?

(c) What interchange of gases takes place between the plant and the atmosphere during the process?

(d) What is the first visible product?

(e) Where does it appear?

10. (a) Describe the appearance and structure of a typical stoma. (b) What is its position? (c) What is its function? (d) How does it act?

11. What is *Cell Sap*? Where does it occur, and what does it contain? What purpose does it serve in the economy of the plant?

12. State the evidence proving the existence of a function of Respiration in plants.

13. What is Cambium? Describe its mode of formation.

14. Describe in general terms the mode in which the manufacture of albuminoids is effected by the plant. From what sources and in what form do plants obtain their nitrogen?

15. Give an account of the distinctive characters of the epidermis of plants. Describe its development and subsequent mode of growth, and mention the organs which may be developed from it.

16. Describe the structure of Cork and the mode of its development.

17. What is a Sieve Tube? What is its structure? What is its position in a Dicotyledon? What is its probable function?

18. How do vascular bundles originate? (a) What is the function of the several parts of a vascular bundle? How does a vascular differ from a fibro-vascular bundle?

19. Briefly describe the histological elements which enter into the composition of a fibro-vascular bundle. What is meant by *open*, *closed*, *concentric*, *collateral*, fibro-vascular bundles? Give examples.

20. Describe Cambium. What positions does it occupy in the stem of a typical Dicotyledonous plant which exhibits secondary growth in thickness? What are its products in these positions? Describe them.

21. Enumerate the principal morphological types of leaf, and their respective functions in the plant economy.

22. Describe briefly—

- (a) the form and character of a typical cambium cell ;
- (b) the mode of development of a vessel from the cambium ;
- (c) the various types of distribution of thickening of the walls of vessels ;
- (d) the probable function of vessels.

23. Describe a typical root system of a Dicotyledon, as regards—

- (a) external conformation ;
- (b) attachment to the soil ;
- (c) distribution of vascular tissue ;
- (d) structure of apex.

24. Give an account of the process of Absorption by Roots. By what means are roots enabled to absorb substances which are insoluble in water ? Enumerate the chemical elements contained in the substances absorbed by the roots which are *essential* to the nutrition of green plants.

25. Write a description of the structure and arrangement of the cells composing the Meristem at the apex of the primary root of any Angiosperm ; specify what plant you have chosen as your type.

26. Give an account of the root of a seedling, with especial reference to the following points : (a) root cap ; (b) root hairs ; (c) mode of branching.

27. Give an account of the external conditions requisite for germination of a seed and growth of the embryo, and explain how these conditions operate.

28. Describe the phenomenon of Heliotropism, and explain its cause.

29. Describe the organs by which a Bean Plant absorbs water, and give an account of the process of absorption.

REPRODUCTION OF THE FLOWERING PLANT.

I.—*The Structure of the Flower.*

§ 61. We have hitherto only considered those structural features of a plant which are related to the existence of the individual ; we come now to those organs which ensure the reproduction of the plant and the continued existence of the species. Most vegetables, even the highest, have, as compared with the higher animals, a remarkable power of reproducing themselves from separated parts. “Cuttings” of most shoots, provided they have buds on them, will grow, send out adventitious roots, and become complete plants. In some cases, *e.g.*, in the begonia, torn pieces of the leaves will even develop a growing point and rootlets, and so become entire individuals.* These methods of spreading are spoken of as **vegetative reproduction**. The offspring usually resemble the parent stock with extreme exactness, and they are therefore of great value to the gardener in propagating and preserving desirable variations. The potato has been grown now for countless generations from cuttings of the tubers. Besides these ways, however, almost all plants produce young by a sexual process.

§ 62. The sexual organs are contained in the **flower**. We may conveniently take such a flower as the common buttercup (Sh. VII.) as an introductory type. On the outside of the buttercup we find a whorl of five green leaf-like parts, the **five sepals**, forming the **calyx**. In the unopened flower

* We may notice here that a *graft* is a cutting placed not in the ground, but in a cleft in the stem of another plant, so that the grafted shoot may establish a physiological connection with its host, and become, as it were, a part of it. Cultivated roses are thus grafted on the vigorous stems of the dog-rose. *Budding* is a similar transfer of buds.

bud these sepals close over and protect the more delicate structure within. Within the calyx cup of the open flower are the very much larger yellow petals—usually five. These constitute the **corolla**, the most conspicuous part of the flower. They are conspicuous in order to attract the attention of insects. If a single petal is examined (Fig. 4), a little excrescence, the *nectary*, will be found at its base, and in this is a minute drop of saccharine fluid, the nectar, which forms a substantial inducement for insects to alight upon the flower. Within the sepals and petals, again, come a host of dark hair-like structures, the **stamens**, or “male” organs, called collectively the **androecium**. At the top of each stamen is a small box, the *anther*, containing a yellow powder, the *pollen*, which is necessary for the formation of seed. Finally, at the centre of the flower is the “female” part, the **gynaeceum**, consisting of a crowd of little hemispherical cases, each made up of a leaf-like structure bent upon itself, and styled a **carpel**. In each of these cases is a small green body, the **ovule**, destined to become the seed, provided a grain of pollen fertilise it. Each carpel is surmounted by a projecting sticky knob to catch this pollen, and called the *stigma*. Now, it is necessary to understand that, although stamens and carpels are thus in close proximity on the same flower, the ovules of the flower are rarely if ever fertilised by their own pollen. Experiment has clearly shown that self-fertilised flowers usually produce feeble offspring, though *why* this should be so is a question to which no satisfactory answer is yet forthcoming. Here this is prevented by the stamens reaching maturity, shedding their pollen, and withering before the gynaeceum is ripe. Insects coming for the nectar of the flower get their bodies dusted with pollen, and take it away to other more mature flowers in the earlier stages, and later bring pollen produced elsewhere to fertilise the gynaeceum. This service is the reason for the presence of the brilliant corolla and the nectary; and wherever we find brilliant, strongly-scented, and honey-bearing flowers, we may rest assured of a similar mutual service between insect and plant.

§ 63. The flattened cone upon which these parts are

arranged is called the **receptacle** (= *thalamus* or *torus*). The successive series of organs follow one another towards the gynoecium at the apex; the sepals form a whorl of five at the base of the cone; the petals usually a whorl of five, alternating * with the sepals and above them; the stamens are in a close spiral and variable in number, as are also the carpels. These organs, as they are seen from above, may be represented in diagrammatic fashion in what is called a floral diagram (Fig. E).

§ 64. We will first notice some points of morphological importance, and some of the most important modifications of this floral structure as a whole, and then we will pass to each of the five series of organs to consider them in detail. We have already called attention to the fact that the different floral organs are regarded as modified leaves. Like leaves, they may be spirally arranged (as are the buttercup stamens), verticillate (as is its calyx), or opposite, but the whorled form is much the commonest. The whole flower of the white water lily is spiral, and sepals pass into petals and petals into stamens in a very instructive manner. When (as is usual) all parts of the flower are in whorls, it is spoken of as a *cyclic* flower, *hemicyclic* when only some parts are verticillate, and *acyclic*, as in the water lily (Fig. VI., Sh. VII.). The receptacle evidently answers to the axis of an ordinary shoot (*cp.* Fig. V., Sh. IX.). When, as in the buttercup, the gynoecium is at the highest point of the flower, and the stamens, sepals, and petals are inserted upon the receptacle below it, it is spoken of as *superior*, and the stamens, sepals, and petals are *hypogynous* (Fig. I., Sh. VII.). In many flowers, however, (dog-rose, *e.g.*), the receptacle rises up round the gynoecium, so as to form a cup, in which the latter lies, and the stamens, petals, and sepals stand on the rim of the cup. The gynoecium is still called superior here, but the stamens, sepals, and petals are *perigynous* (Fig. II., Sh. VII.). The cup may be very deep (as in the rose), or shallow (as in the strawberry and bramble), and in the latter case it is sometimes hard to tell from the hypogynous type. In the

* *I.e.*, one opposite each gap between two sepals.

hypogynous type, however, the sepals can usually be removed completely without affecting the stamens, while in the perigynous the sepals drag the stamens with them. Indeed, the term *episepalous* is often used as a synonym for perigynous, and the receptacle cup has been regarded as a calyx. Finally, the ovary may be sunk into the receptacle, and without any proper wall of its own. It is then called *inferior*, and the other parts of the flower *epigynous* (Fig. III.).

§ 65. A flower may have only a single whorl of non-essential organs, when it is *monochlamydeous* (Fig. VI. E, Sh. X.), and the whorl is then called the calyx; or it may be altogether destitute of the floral envelopes (*achlamydeous*) (Sh. IX. 8, ff.). Where its floral envelopes are similar in appearance, the term *perianth* is used. If either of the sets of *essential* organs (*i.e.*, androecium or gynoecium) are absent, it is *diclinous* (= unisexual, Fig. IX., Sh. VII.). *Hermaphrodite* (having both sexes) is the usual condition. *Monoecious* plants have diclinous flowers of both sexes on the same plant; *dioecious*, one sex only on each plant. *Polygamous* plants have male, female, and hermaphrodite flowers. The oak and birch are *monoecious*, the willow *dioecious*, the elm *polygamous*. If the petals of a flower are separate, so that one can be removed without affecting the others (*rose*), they are called *free*, and the corolla *poly-petalous*. If they are united together by their edges (*primrose*), the corolla is *gamopetalous*. *Polysepalous*, *gamosepalous*, are equivalent terms for the calyx, and *polyphyllous*, *gamophyllous*, for the perianth.

§ 66. Usually the more conspicuous parts of a flower are arranged radially round a centre, like the spokes of a wheel. It is then called radially symmetrical or *actinomorphic*. But sometimes, as the orchid or pea, the parts balance about a middle line which divides them into two equal halves, and they are symmetrical about no other axis. They are then called *zygomorphic*. Or they may be altogether *asymmetrical*, as in the cactus.

§ 67. The student having read thus far will be in a

position to understand the following rough skeleton of the classification of flowering plants. Under each division certain common and easily accessible types are named, and upon some of the actual flowers he should verify what is here given.

PHANEROGAMS (see § 44).

- A. **Gymnosperms** (type, *Pinus*) have no "true" flowers or fruits, and the ovules are *not enclosed in an ovary*.
- B. **Angiosperms** (= Flowering Plants), having a true flower on a more or less *flattened receptacle*, with ovules *enclosed in an ovary*.

B. 1. *Dicotyledons*.

The vascular bundles *open* and almost invariably in a ring; the leaves *reticulate*; the parts of the flower *may* be spiral, or in whorls of two, four, or five, rarely in threes; the embryo with two cotyledons.

(α) **Polypetalae.**

As the name implies, polypetalous.

i. **HYPOGYNÆ.**

Water lily, buttercup, anemone, monk's-hood (zygomorphic), poppy, shepherd's-purse, wallflower, cress, honesty, mustard, violet (zygomorphic), *Lychnis dioica* (dioecious), sweet-william, chickweed, pink, lime, mallow, geranium, mignonette, garden nasturtium.

ii. **PERIGYNÆ.**

Pea, broom, laburnum, lupine, acacia, bean, rose, strawberry, apple, pear, bramble, almond, plum, cherry.

iii. **EPIGYNÆ.**

Parsley, celery, fennel, carrot, parsnip, hemlock, caraway, cactus.

(β) **Gamopetalae.**

Gamopetalous.

i. **HYPOGYNÆ.**

Convolvulus, heath, primrose, forget-me-not, dead nettle, ground ivy, tomato, potato, snap-dragon, foxglove, speedwell.

ii. **EPIGYNÆ.**

Honeysuckle, thistle, cornflower, daisy, dandelion, sunflower, zinnia, marigold, currant, gooseberry.

(γ) **Apetalae.**

Monochlamydeous or achlamydeous. Often
dichlinous.

i. **HYPOGYNÆ.**

Stinging nettle, mulberry, elm, willow,
poplar, spurge, laurel, sorrel, dock.

ii. **PIGYNAE.**

Oak, mistletoe.

B. 2. *Monocotyledons.*

The vascular bundles are *closed*, and appear scattered over the stem in cross section; the leaves usually with parallel veins; parts of the flower in threes *usually*; the embryo with *one* cotyledon.

(α) **Petaloideæ.**

Petals conspicuous.

i. **HYPOGYNÆ.**

Bluebell, lily, hyacinth, onion, tulip,
lily of the valley.

ii. **PIGYNAE.**

Iris, crocus, orchis, daffodil, narcissus,
snowdrop.

(β) **Nudifloræ.**

Perianth absent or *scaly*.

Arum (= "lords and ladies"), maize,
wheat, oats, all grasses, sedge, palms.

§ 68. We may now proceed to consider the chief modifications the sepals, petals, stamens, and ovary undergo through this series of flowers. We will commence with the **calyx**. This may be *polysepalous* or *gamosepalous*. Occasionally it is coloured* after the fashion of the petals, and is then *petaloid*, as in the monk's-hood. It may be produced into a spur, as in the canary creeper and nasturtium. A gamosepalous calyx may be *tubular* or *inflated*. The shape of the sepals in a polysepalous calyx may, if necessary, be indicated by the same terms as are used for leaf forms (§ 33).

§ 69. The **corolla** may be described as *zygomorphic*, *actinomorphic*, *irregular* (horse chestnut and cactus), and as *polypetalous* or *gamopetalous*. In polypetalous corollas

* "Coloured" in botany means white or any colour but green. Green is not considered to be a "colour" in the descriptive use of the word.

SHEET VII.

Diagrams of (1.) a hypogynous, (2.) of a perigynous, and (3.) of an epigynous flower.

4. Buttercup flower dissected. A., a separated petal with nectary at base. B., section of flower, sepals removed; car., the apocarpous gynoecium; st., the stamens. C., a carpel in section; stig., the stigma or the ovule. D., ripe fruit (achene) and albuminous seed therein; emb., the embryo. E., diagram.

5. (a) The fruit of the poppy (porous capsule) with its sessile stigma; p., the pores by which the seeds escape. (b) A floral diagram of the poppy, the two sepals fall off as the flower ripens.

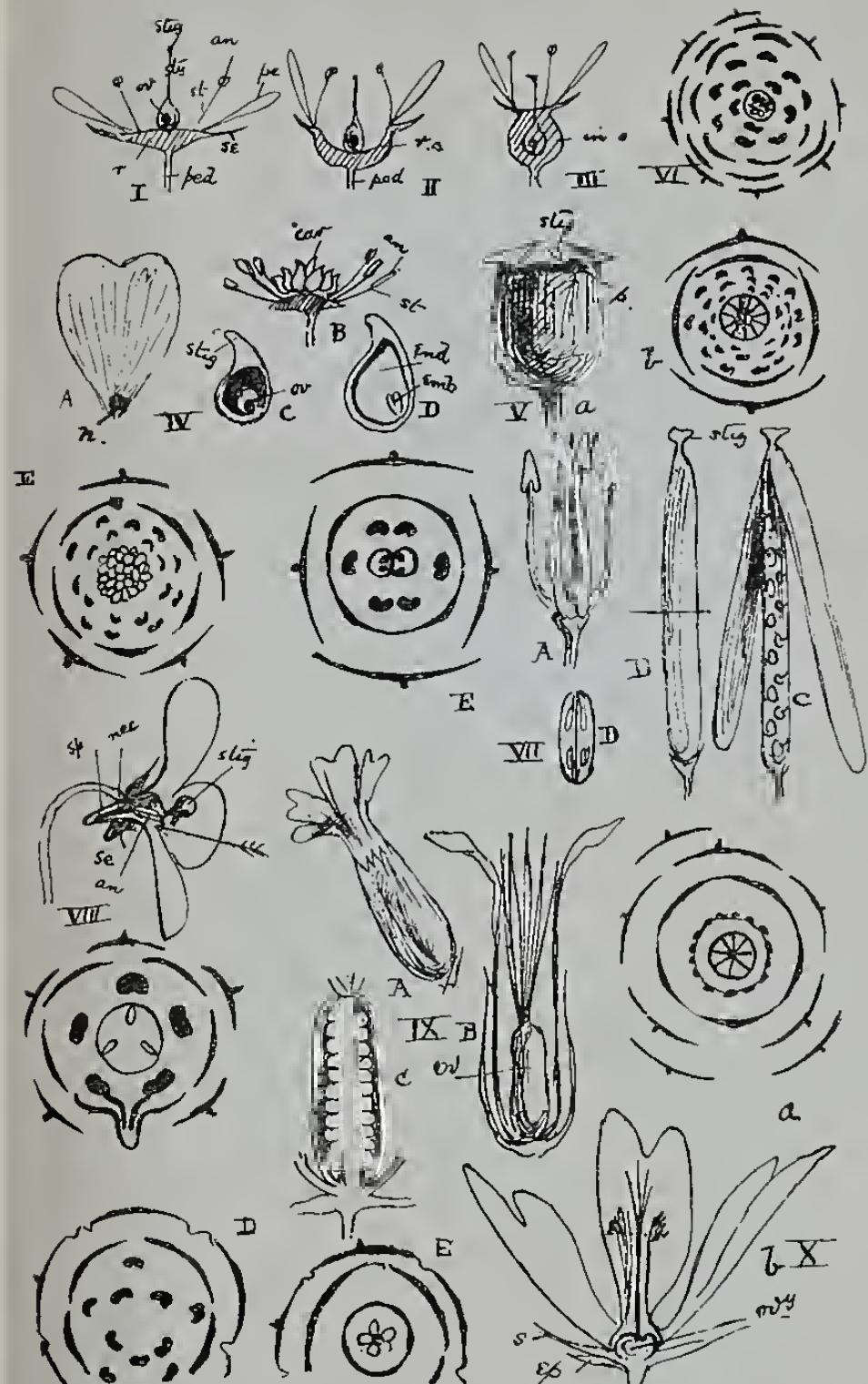
6. Floral diagram of the water lily—an acyclic flower.

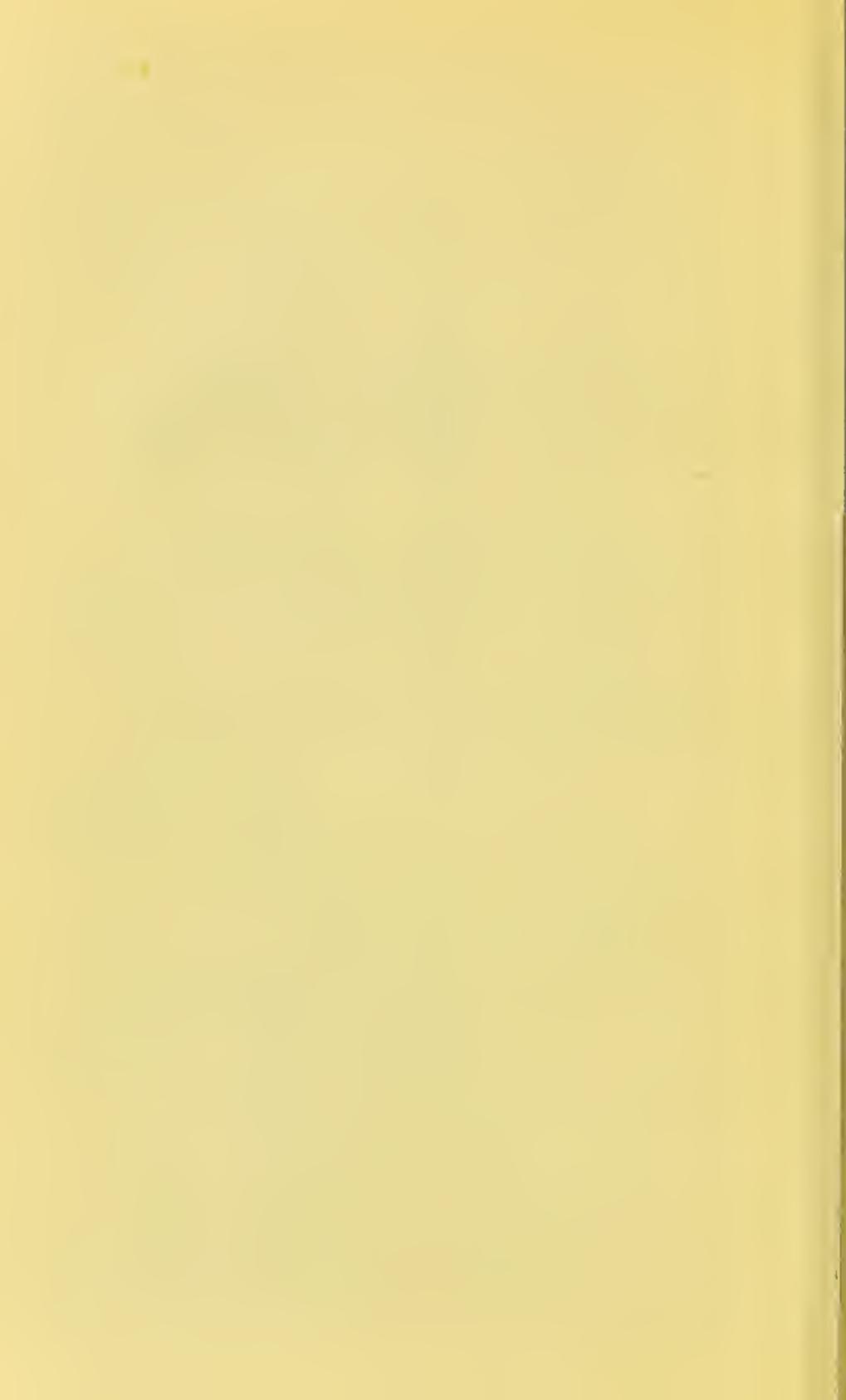
7. Flower of a crucifer (wallflower, e.g.). A., the tetradynamous androecium. B., the gynoecium. D., the same in section to show the false dissepiment. C., dehiscence of the stigma. E., floral diagram.

8. Violet flower in section; note the lid-like stigma. The arrow shows direction of entry of the insect; nec., nectary in sp., the corolla spur. A diagram below the figure.

9. Lychnis dioica. A., Female flower. B., the same in section. C., ovary cut to show free central placentation. D., Diagram of male, and E., of female flowers.

10. Common wayside mallow, with monadelphous stamens and epicalyx. (a) Diagram, (b) flower.





the petals may (as in the pink and carnation) have a wide flattened upper portion and a long narrow part which is attached to the receptacle. The former is called the *limb* and the latter the *claw* (Fig. IX. b, Sh. VII.), and the petal is “clawed.” As with the sepals, the terms used for leaf shapes are applicable here. The *papilionaceous* corolla is distinctive of the British representatives of the order Legumenosae (= pod-bearers, the pea, bean, vetch, lupine, laburnum, broom, clover, etc.). In this (Fig. I., Sh. VIII.) the upper (*posterior*) petal is large and called the *standard*, the two side ones form the *wings*, while the two lower (*anterior*) fuse to form a *keel*. Among gamopetalous corollas we may notice the *hypocrateriform*, shaped like the primrose; the *labiate*, with an upper and under lip, as in the dead nettle and snap-dragon; and the *campanulate*, like a bell (harebell).

§ 70. The *stamens* may be *hypogynous*, *perigynous* (= *episepalous*), or *epigynous*; or they may fuse with the petals and be *epipetalous* (honeysuckle, foxglove, dead nettle, sunflower). The arrangement may be spiral and the number variable or *indefinite*, or there may be one or more whorls having a *definite* number. Typically the anther appears externally to consist of two lobes, and it is balanced on a stalk or *filament* (Fig. VI., Sh. XI.). The body of the anther may swing like the head of a T on the filament, and is then *versatile*; or the two things may be in the same straight line, and it is then either *connate* or *innate*, as the filament is or is not produced up between the lobes. Or the filament may be absent and the anther *sessile*. The splitting of the anther lobes to release the pollen is called *dehiscence*. Usually this is a longitudinal splitting, which, when directed inwardly, is called *introrse* dehiscence, and outwardly *extrorse*. The barberry anthers *dehisce* by peculiar lateral lid-like *valves*; those of the various heaths *dehisce* by *pores*. The stamens may be entirely separate from each other (*free*), or their filaments may unite to form a single tube (*monadelphous* stamens, Fig. X., Sh. VII.),* or there may be

* In the mallow, a five-petalled, pinkish-lavender-coloured roadside flower—June, July.

two bundles (*diadelphous*),* or even more groups (*polyadelphous*).† In the *Compositae* (daisy, sunflower, thistle), an order of Epigynous Gamopetalae, of which we shall have to say more presently, the *filaments* are not united, but the *anthers* are (Fig. VIII., Sh. VIII.), into a cylinder round the style. This form of androecium is called *syngenesious* (also in lobelia). There are two forms of androecium characteristic of certain marked natural orders of flowers to which special names are given. The first of these is the *tetradynamous* androecium. This occurs in the wallflower, lady's-smock, shepherd's-purse, cress, and, indeed, to all plants belonging to the order Cruciferae, a section of Polypetalous, Hypogynous Dicotyledons. There are six free stamens, of which two are usually of a different length to the remaining four.‡ These two are opposite one another in the flower, and the others are arranged in two opposite pairs, as shown in the figure (*A*) and floral diagram (*E*), Fig. VII., Sh. VII. The *didynamous* androecium has two long and two short stamens, and it occurs in a great series of Hypogynous, Gamopetalous Dicotyledons, of which the dead nettle is a convenient type. Sometimes in these orders the number of stamens is further reduced to two, as in the garden sage. Occasionally structures occur which from their position are recognisably stamens, but which have no anther lobes. These sterile stamens are called *staminodes*. We find them in the orchid, for instance. The two lobes of an ordinary anther are joined by a tract of tissue, the *connective*. This is usually simply a suture between the lobes, but in the garden sage it is greatly elongated.

§ 71. The *gynoecium* § may consist of one (= *monocarpellary* gynoecium) or several (= *polycarpellary*) carpels. The former is the case with the pea, bean, and other pod-bearing flowers. The carpels of the polycarpellary ovary may all be separate from each other, and each form a little case

* The pea, e.g., Fig. I., Sh. VIII., which has ten stamens, nine united together and one free.

† Occurs among common British flowers only in the St. John's wort, a yellow roadside flower with dotted dark-green leaves and one-sided petals.

‡ Almost the same length in wall flowers.

§ "Pistil" is often used as a synonym.

SHEET VIII.

1. Pea flower (Zygomorphic). A., showing standard, *std.*; *al.*, ala; and *k.*, keel. *ex.*, calyx. B., Androecium and gynaecium. C., section of gynaecium. Floral diagram 6 below.

2. A., receptacle cup (*r.*) apocarpous gynaecium (*ovr.*) calyx *se.* and stamens (*st.*) with cordate anthers, of the dog rose. B., a single carpel.

3. Pome.

4. Diagram of flower of plum to contrast with pome producing flower.

5. 1. section of strawberry flower--note epicalyx. 2. a single carpel. 3. the pseudocarp.

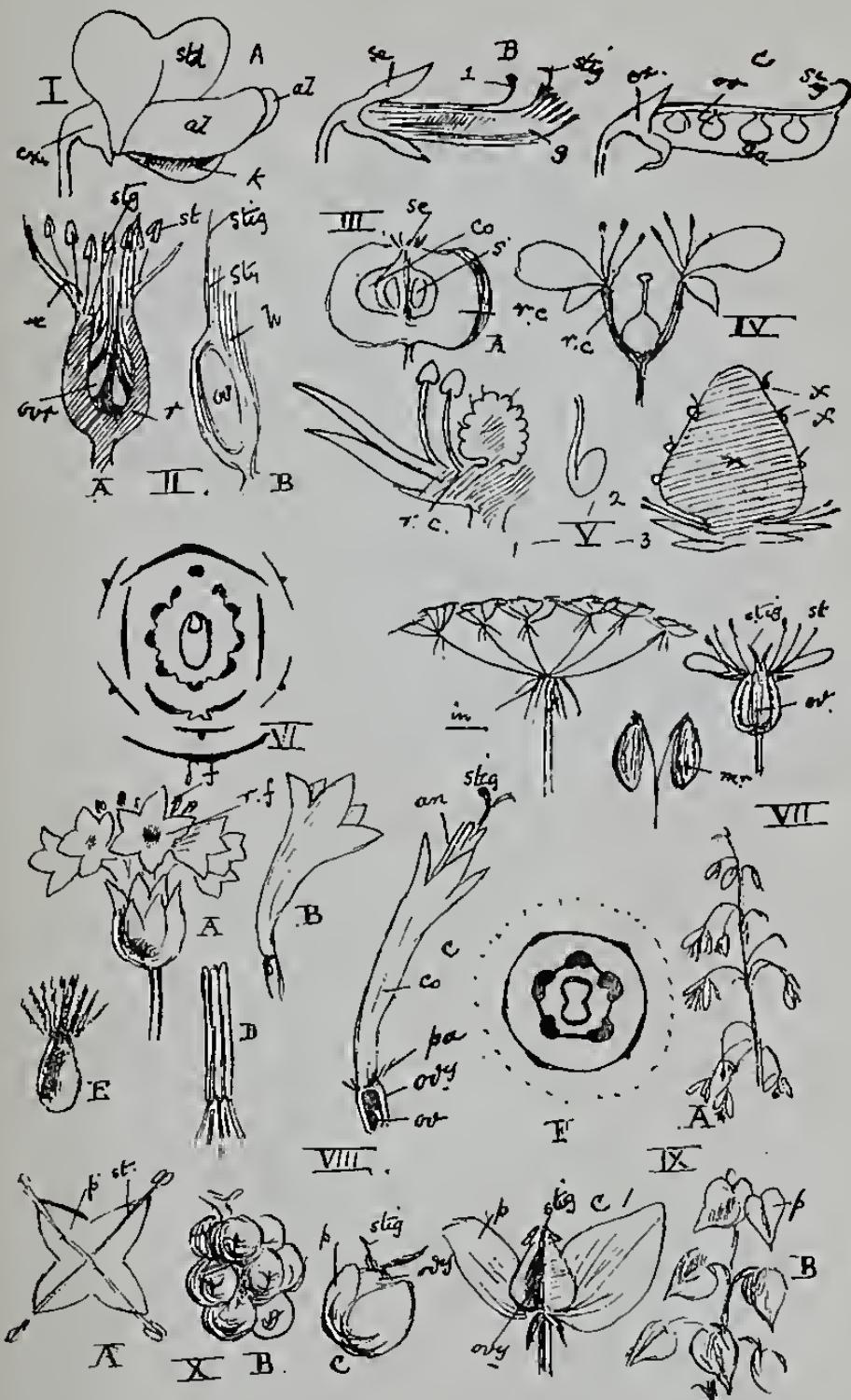
6. Pea—diagram.

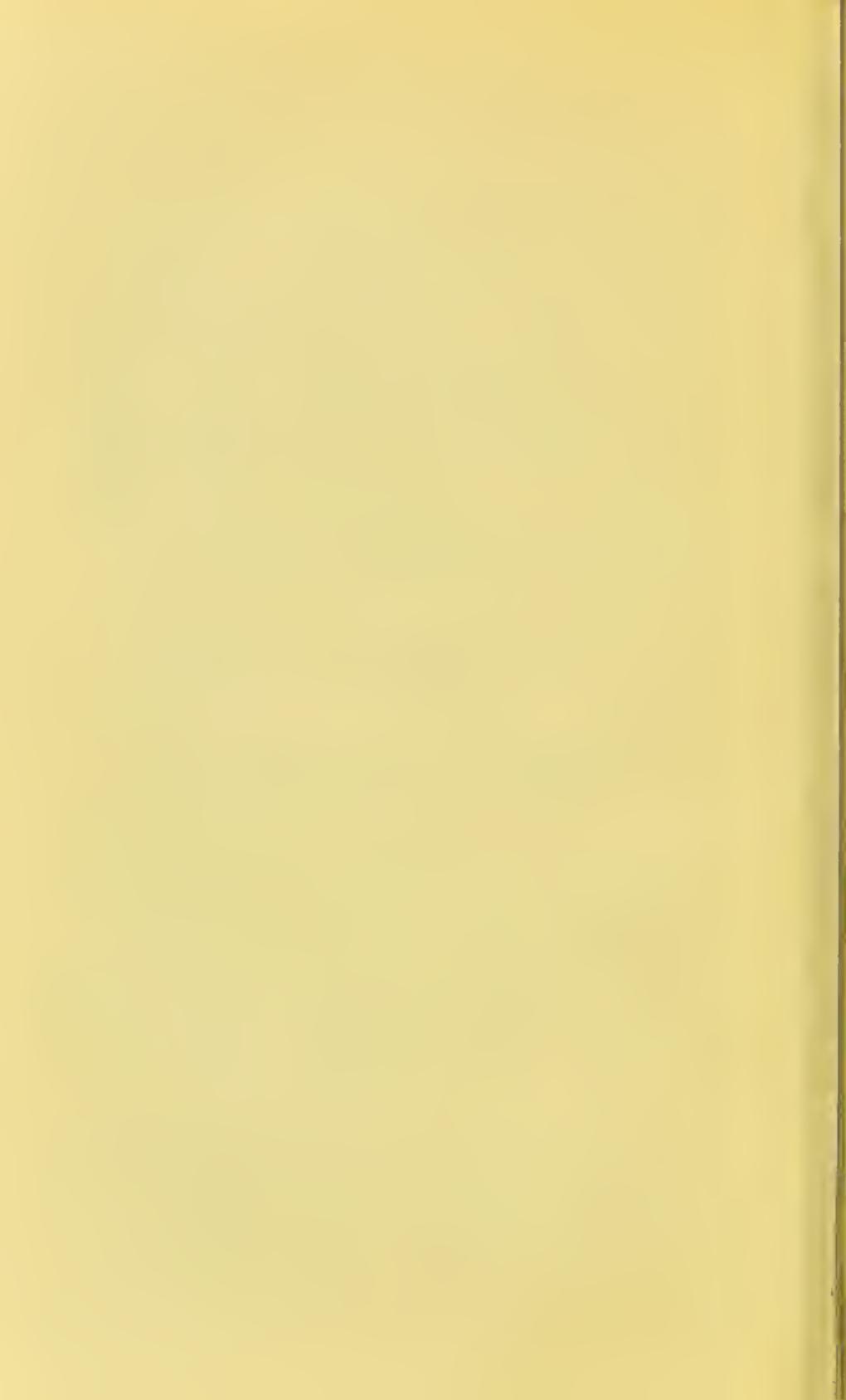
7. Inflorescence (compound umbel) of an umbellifer, *e.g.* fennel or carrot, section of flower (note almost abortive calyx) and single fruit (*cremocarp*).

8. A., Capitulum. B., sterile ("ray") floret. C., fertile ("disc") floret. D., gynaecium. E., fruit, and F., floral diagram of the corn-flower. *pa.*, pappus=calyx.

9. A., Male, B. Female, raceme of Sorrel (*Rumex*). C., Female flower. *p.*, perianth.

10. A., Male flower. B., Female inflorescence; and, C., Female flower of mulberry.





for ovules by itself, as in the buttercup (*apocarpous*), or they may unite to form one central structure (*syncarpous*). The syncarpous gynoecium (Fig. VIII., Sh. XI.) may consist of several carpels united by their edges to form one chamber, as in the primrose and pink (*unilocular*). Or the space may be subdivided into two, as in the wallflower (*bilocular*), or more chambers (*multilocular*), as in the lily and mallow. The partitions (= dissepiments) between the several chambers or *loculi* of a multilocular ovary are usually formed by the inturned edges of the carpels, as in the lily; but occasionally the dissepiments are not of this nature, and then they are called *false dissepiments* (Fig. VII. D, Sh. VII.). In the mistletoe the inferior ovary has no cavity, since the solitary ovule devoid of the usual integument adheres to its wall.

§ 72. The arrangement of the ovules in the cavity of the gynoecium is called *placentation*; the region of their attachment the *placenta*. This may be in the axil of the carpel, as in the buttercup (*axillary*). Commonly they are attached to the edges of the carpels. For this the term *marginal* placentation is employed. Two special cases of *marginal* placentation are, *parietal* (Fig. VIII., Sh. VII.), where the placentae occur on the walls of a unilocular syncarpous ovary (violet, pansy), and *axile*, where by the inturnings of the carpels to form true dissepiments (Fig. VI., Sh. IX.) they are at the centre of the ovary (lily). *Superficial* placentation indicates an irregular distribution over the ovary wall. The gathering together of the ovules *upon a column* in the centre of the unilocular ovary (Fig. IX. C, Sh. VII.) is distinctive of the Primulaceae (primrose), and is seen also in the fully developed flowers of Caryophyllaceae (pink, carnation, ragged robin, chickweed). This is *free central* placentation. The placentation of a solitary ovule at the bottom of the unilocular ovary is *basilar*, as in the Compositae (sunflower, daisy, thistle, Fig. VIII., Sh. VIII.).

§ 73. The stigma is commonly a sticky expansion upon the end of the style. The style is absent and the stigma is *sessile* in the poppy and buttercup. Where fertilisation

is not effected by insects, but by the wind, as in the grasses, the stigma is often large, conspicuous, and feathery.

§ 74. There are certain structural abnormalities which may perhaps be noticed here. In the daffodil we find, internal to the perianth, a tubular petaloid upgrowth, enclosing the style and stamens, and called the *corona* (Fig. VI., Sh. IX.). There is also a crown of ligule-like rays in the passion-flower. The stamens and ovary of *Lychnis dioica* and some of its relatives are lifted up on a kind of stalk above the insertions of calyx and corolla. In the orchid the stamens and ovary form a central pillar. What are called *double flowers* have either intercalary rows of petals or the stamens become petaloid.

§ 75. The flower stalk is called the *peduncle*. Where it is absent the flower is *sessile*. Upon it there may appear small herbaceous or coloured leaves or leaf parts, the *bracteoles*. Small leaves that come immediately beneath the calyx are called the *epicalyx*, as in the mallow (Fig. X., Sh. VII.). The peduncle usually springs from the angle between a leaf and the stem. This leaf is the *bract*; it may be exactly like any other foliage leaf, or it may differ in shape and size, or even be scaly or petaloid (*i.e.*, coloured). When the bract is absent the flower is *ebracteate* (forget-me-not). Flowers may be *solitary*, *i.e.*, springing by themselves from the general vegetative system; but more often they are gathered together upon a special branching system, the *inflorescence*. It is in inflorescences that the bracts become most specialised and important. A whorl or whorls of bracts, such as we shall presently describe as occurring in some of the inflorescences of the Umbelliferae and in the Compositae, is called an *involute*.

§ 76. We may note here the use of the words *anterior* and *posterior* in botany. In zoology they indicate the direction which is usually forward in the progression of a free-moving bilateral animal, and the reverse, respectively. In botany, where the forms are usually not free-living but fixed, their purport seems to be entirely different; it is

the main growing point, apparently, of the stem structure that is regarded by botanists as the most posterior point. Hence, if a flower terminates the main axis of a shoot, its calyx, to be consistent, should be spoken of as anterior to its corolla. When the flower branches off from the main axis (in a racemose inflorescence), the side towards that axis, the inner upper side that is, is posterior. Thus the standard of the pea flower is *posterior*, the keel *anterior*; the upper lip of the dead nettle is *posterior*, its lower *anterior*. The *antero-posterior plane* of the flower is a vertical plane containing the centre of the flower and the main stem. In a floral diagram the position of the main axis with regard to a flower is indicated by a dot, the bract by a petal-like stroke (Fig. VI., Sh. VIII.). Commonly, however, botanists do not use these terms anterior and posterior with reference to any but lateral structures.

We may also note that the majority of botanists spell gynaeceum "gynoecium." It really does not matter how the word is spelt so long as it is recognisable; but as an actual Latin word, gynaeceum or gynaecium, existed, there seems to be no reason why we should employ the new barbaric form.

II.—*The Inflorescence.*

§ 77. Where flowers are gathered together in inflorescences, we can recognise two chief types of branching. In one the primary axis gives off one or several side buds, and ends in a flower. These lateral buds give rise to secondary shoots, which terminate again in flowers, after giving off lateral buds. These ternary buds again repeat this process. This is cymose branching, and the inflorescence is called *cymose* or *definite*. The apical flower opens first, the lateral follow. When in a cymose system the lateral buds appear in pairs (Fig. VII. 11, Sh. IX.), we have a Biparous Cyme. Or a single bud may appear at a time, and either continually on one side (Helicoidal Cyme, Fig. 10) or alternately (Scorpioidal Cyme, Fig. 9). These latter forms may straighten out to form a kind of false main axis (*pseud-axis*). The helicoidal cyme then resembles an ordinary and the scorpioidal a one-sided raceme (to be presently described); but the position of the bracts is different in the two cases (Fig. VIII.). When a cymose system gives off branches in opposite pairs, it is a *dichasium*; when there are more than two branches, it is a *multiparous cyme*.

§ 78. In the *indefinite* or *racemose* inflorescence the main axis never terminates in a flower, but commonly continues to grow and form fresh flowers laterally. It is represented typically by the *raceme* (Fig. VII. 1). The raceme may be *simple*, as figured, or its branches may be themselves racemes (*compound raceme*). In the raceme the flowers are pedunculate. If they are sessile, the inflorescence is not called a raceme, but a *spike* (Fig. 2). A fleshy spike, which is deciduous (shed early), and which usually bears imperfect flowers, is called a *catkin* (= *amentum*). The arum lily (Fig. 8) and its humbler wayside cousin "lords and ladies" have an erect fleshy spike, bearing extremely reduced unisexual flowers, which are simply anthers and ovaries respectively,

and the whole is enclosed by a large bract. To this sheathing, usually coloured leaf, subtending this inflorescence, the name *spathe* is given, and this particular form of spike is termed the *spadix*. A *corymb* (Fig. 4) is a raceme in which all the flowers are upon the same level. A *panicle* is an irregular compound raceme. In the *umbel* (Fig. 5) the side branches come off in whorls; and the primary axis, though it remains evidently the main stalk of the system, is shortened. The umbel may be *simple*, or the secondary branches may be again umbels, in the *compound umbel*. This inflorescence is very distinctive of a great order of *Epigynous Polypetalae*, the *Umbelliferae* (all forms named in § 67, under B. 1, (a) iii., except the last). When the main inflorescence axis becomes flattened down, and the flowers upon it are sessile, we have the *capitulum* (Fig. 6). This occurs in the well-known teasle, where the individual flowers have spiny bracts and the capitulum is called *paleate*, and in the order of the *Compositae* (= sunflower, daisy, marigold, chrysanthemum, thistle, dandelion, cornflower), where the individual flowers are often *ebracteate*. The fig (Fig. 7) has a sort of hollow capitulum, containing crowds of unisexual flowers.

§ 79. We may, perhaps, notice the structure of a Composite *capitulum* a little more fully. These capitula are good examples of the association and reduction of individual flowers to form a higher unity. They are popularly regarded as single flowers, and they are eminently calculated to exercise the mind of a student labouring under that impression. Outside such an inflorescence as that of the corn-flower (Fig. VIII., Sh. VIII.) comes the *involucre*, a series of bracts without flowers in their axils. Within this come a number of sterile (neutral) flowers (ray florets), which are simply conspicuous nectariferous corollas. Inside this circle is the disc of perfect flowers (disc florets), the older being of course towards the circumference of the disc, and the younger to the centre. Each flower is epigynous; the calyx is greatly reduced and almost altogether absent; the corolla, gamopetalous, five-toothed, and tubular; the stamens, epipetalous and syngenesious; the ovary, inferior, unilocular, with basal placentation. In the daisy, while the yellow disc

florets follow this type, the (white) ray florets are zygomorphic, and drawn out into a strap shape. This latter form of floret is called *ligulate*. All the florets of the dandelion are ligulate.

§ 80. The flowers of wheat, rye, maize, and the grasses (= Graminaceae, Monocotyledons, Nudiflorae) are grouped in a special way. Small spikes of flowers called **spikelets** are arranged in spike or raceme fashion upon the main stem. Each spikelet has two large bracts, the *glumes*, at its base. The individual flowers may be sterile, unisexual, or hermaphrodite. In the panicle of the cultivated oat (Fig. III., Sh. IX.) there are two flowers in each spikelet, the one sterile, the other hermaphrodite. Each flower is protected by two *pales*, the outer of which is to be regarded as a bract, the inner as a bracteole. The perianth is reduced to two small hypogynous scales, the *lodicules*. There are three hypogynous stamens with versatile anthers, and a unicellular gynoecium with two feathery stigmas.

§ 81. The common spurge (*Euphorbia*), which we have already mentioned as possessing lactiferous cells, in which dumb-bell-shaped starch grains are found, has inflorescences that might very easily be mistaken for single flowers. The individual inflorescence is called a **cyathium** (Fig. I., Sh. X.). It is surmounted by a pedunculate female flower, consisting simply of a trilocular gynoecium. Beneath this are numerous male flowers, simply single stamens. The whole is enclosed by an involucre with a fleshy border. The flower of the box is similar to this.

§ 82. There are certain inflorescences spoken of as mixed, in which cymose systems are arranged in a racemose manner. The thyrus (of the horse chestnut) is such a raceme of cymes. In the dead nettle the flowers are in very short cymes, which are arranged in a spike-like manner at intervals along the main axis. The inflorescence of the rush is corymbose, and may or may not be an abbreviated cyme.

SHEET IX.

1. Shoot of the Butchers' Broom, showing leaf-like stem, *cladodes*, cl. fl., a flower. br., bracts.

2. Inflorescence (*locusta*) of Oat. gl., glumes. p. i., inner pale (bractcole of fertile flower). p. o. (its bract), outer pale. St. F., sterile floret.

3. (a) A single flower and its pale. (b) fruit (caryopsis) in section. end., endosperm. sc., scutellum. pl., plumule. r., radicle. (c) floral diagram. At the base of ovary are the two small scales, the *todicules*. See § 80.

4. Diagram of the Autumn Crocus flower for comparison.

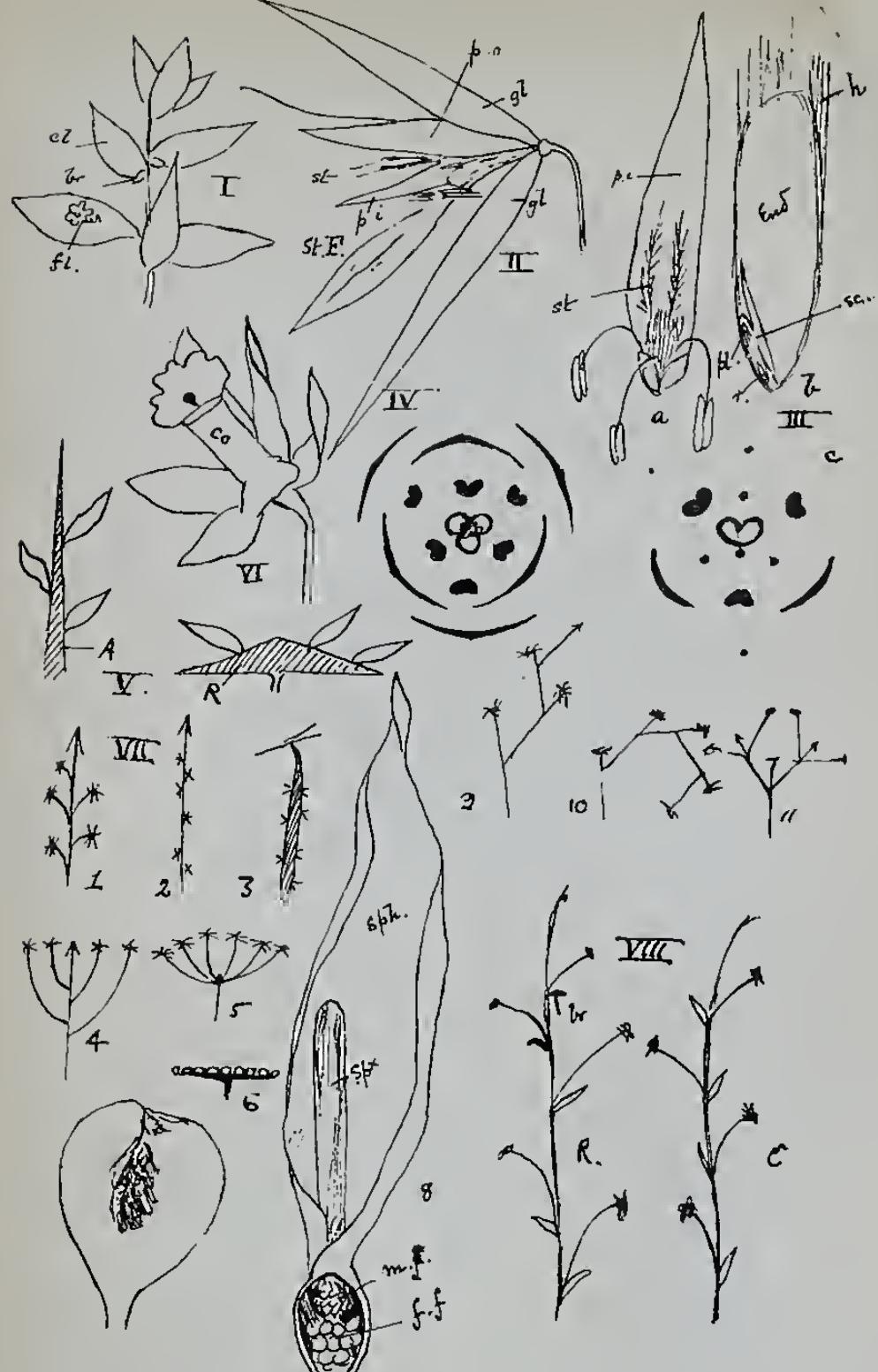
5. Diagram to illustrate how the axis A. of an ordinary vegetative shoot is represented by the receptacle (R.) of a flower.

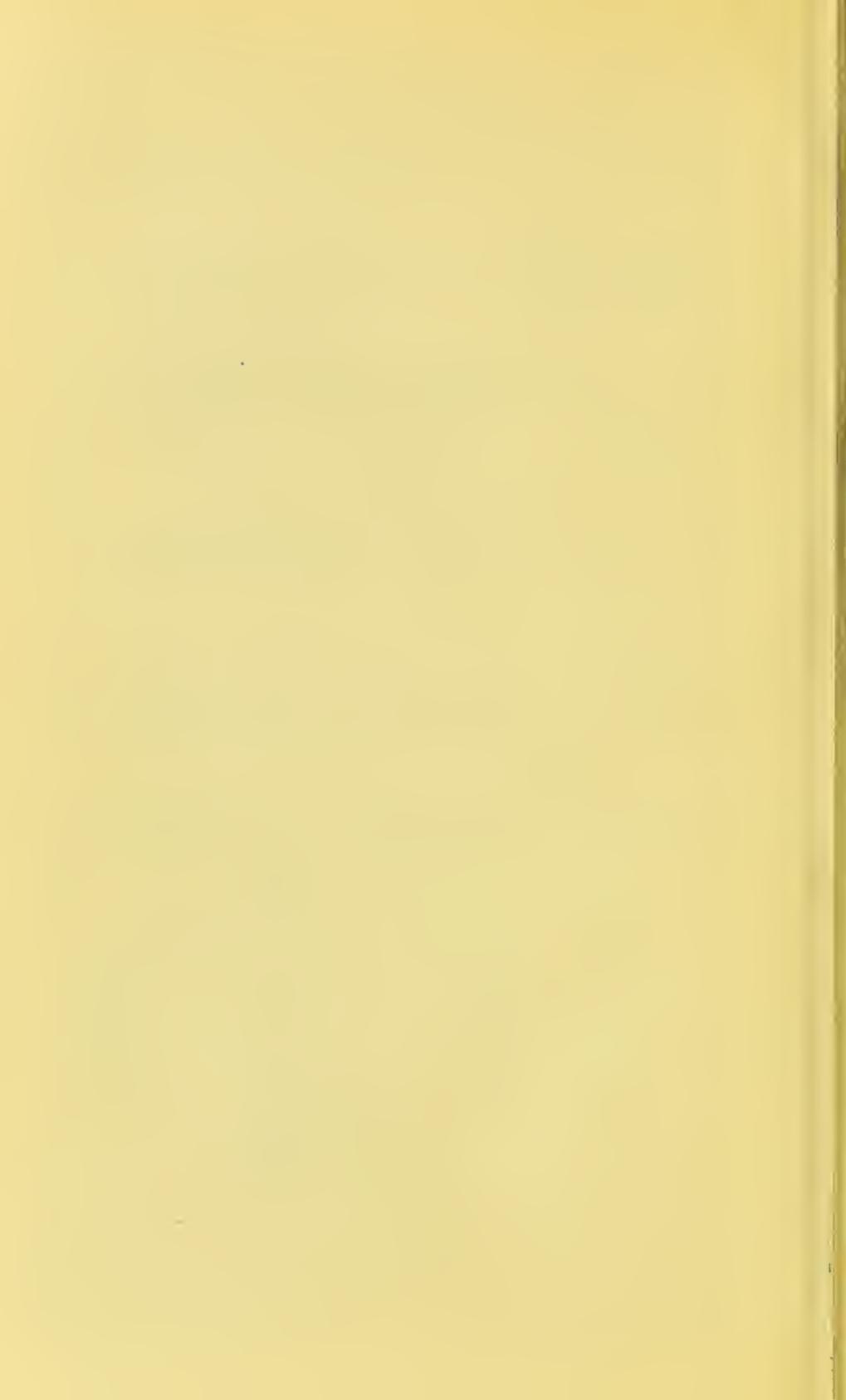
6. Narcissus, showing corona, co.

7. INFLORESCENCES. 1. raceme. 2. spike. 3. catkin. 4. Corymb. 5. Umbel. 6. Capitulum. 7. Fig inflorescence. 8. Arum inflorescence. m. f., male, and f. f., female flowers. 9. Scorpoidal cyme. 10. Heliocoidal cyme. 11. Dichasium.

8. A raceme and a cyme with appendages for comparison. Note the position of the bracts.

To face page 50.





CLASSIFICATION OF INFLORESCENCES.

A. Monopodial—

I. Racemose or Indefinite—

*Elongated axis.**Pedunculate flowers* (Raceme, Panicle).*Sessile flowers* (Spike, Catkin).*Abbreviated axis.**Pedunculate flowers* (Umbel).*Sessile flowers* (Capitulum).

II. Cymose—

One flower at node, false axis (Helicoidal, Scorpoidal),*Two flowers at node* (Dichasium).*Three or more* (Multiparous Cyme).**B. Dichotomous—**

(?) Certainly rare.

III.—*Pollination and Formation of the Fruit.*

§ 83. We have already called the reader's attention to the fact that in the buttercup the conspicuous corolla and the nectary are connected with the necessity for the transfer of pollen from one plant to another and its accomplishment by insects, and we have stated that in all cases a conspicuous corolla and nectary imply a similar mutual service between the plant and some animal, bee, moth, hummingbird, or fly, as the case may be. This transfer of pollen to the stigma is called *pollination*. In some cases the pollen is dry and (since much of it must be wasted) very abundant, the stigmas large, feathery, and sticky, and the transfer is effected by the wind. In this *anemophilous* pollination there is no need for conspicuous or odoriferous corolla or for nectaries, and the flowers are usually inconspicuous. In *hydrophyllous* cases the pollen floats on the water. But *zoophilous* methods, or pollination by animals, are among flowering plants the most frequent. Usually the animal is an insect, and then the pollination is called *entomophilous*.

§ 84. The accident of self-pollination is guarded against usually by the fact that androecium and gynoecium do not become mature together. The former is usually the first to develop (*protandrous flowers*), but rarely the gynoecium is first mature (*Aristolochia*), when the flower is said to be *protogynous*. *Dichogamy* is a term covering protogyny and protandry. Such open actinomorphic flowers as the buttercup are visited by great numbers of different insects, and are doubtless put under contribution by many forms that do little to distribute the pollen advantageously. **Unwelcome** (because unprofitable) visitors are avoided in many cases by special contrivances: in the orchids, for instance, the nectar lies in a deep tubular spur which can only be reached by the long tongues of special species of moths. The streaks of colour on the lip of the orchid flower, and

similar veins and splashes of tint elsewhere, probably in many cases guide the selected insect to the nectary. The refined sense of colour of many of the more specialised insects enables them to perceive blue and violet-coloured flowers which are inconspicuous to the common herd of insects. Green, white, yellow, red, and blue mark successive stages in the specialisation of flowers to insect visitors.

§ 85. Among special contrivances we may notice the case of the primrose, which has two types of flower, both hermaphrodite, and differing only in the relative length of style and stamens (*heterostyly*). In one form ("long style" flowers) the round stigma lies in the throat of the tubular corolla, and the epipetalous stamens are half-way down the tube; while in the "short style" flowers the stigma is half-way down the tube and the anther at the throat. An insect becomes dusted with pollen by one type of flower on the spot of its body which will be opposite the style of the second type. Hence fertilisation will not occur between flowers of like, but only between flowers of unlike form. This is spoken of as *dimorphism*. *Lythrus* is *trimorphic*, and has three forms of flower.

§ 86. The violet (or pansy) has a pretty mechanical contrivance (Fig. VIII., Sh. VII.). The round stigma has a kind of lid, which is opened by any insect pushing *into* the flower, but shut by the animal's withdrawal. Hence an insect can pollinate on entering, but not on leaving, when it would be likely to have the flower's own pollen from the anthers at *an*.

§ 87. To guard against the catastrophe of the flower not being fertilised, the violet also bears inconspicuous self-fertilising flowers which never open, and which may form seed in that case. Such flowers are called *cleistogamous flowers*.

§ 88. If any one examine a pea or scarlet runner (Fig. VIII., Sh. VIII.), and press gently on the alae, the stigma

emerges, and if an insect were upon the alae it would strike its abdomen and then curve over, the stamens next striking the insect. Hence the pollen is dusted on the insect *after* the stigma has been touched, and is ready then for the stigma of the next flower visited.

§ 89. The arum lily and the common roadside arum ("lords and ladies") have a slightly putrid smell. They avail themselves of the services of the small flies which find this odour attractive. The spadix and spathe are seen in Fig. VII. 8, Sh. IX. We have sterile flowers pointing down and making a kind of lobster trap of the lower part of the spathe. At the base come female flowers, which are ripe first; and above, male flowers. The fly crawls into the trap below when the female flowers are ripe, and is only released by the withering of the spathe after the ripening of the male flowers. All the captives collected by that time fly away with pollen, and being insects of lowly intelligence, undergo in some cases the same experience elsewhere, and so effect fertilisation.

§ 90. After pollination the ovule develops, as we shall presently describe, into the seed; the ovary becomes the fruit. The word fruit is used in botanical literature in a sense quite different from its popular import. The cucumber, the tomato, the pea pod, loofah, caraway seeds, and Indian corn are fruits; the apple, pear, pineapple, and mulberry are not true fruits. A fruit to the botanist is merely the *post-fertilisation form assumed by the gynoecium*. Such a thing as the apple, which contains the seeds, but includes other parts of the floral structure as well as the ovary, is called a false fruit, or *pseudocarp*. We will consider various pseudocarps later; it will be convenient first to give a classification of true fruits.

§ 91. The developed ovary wall, we may note here, is in the fruit spoken of as the *pericarp*. The fruits are either *dry* or *succulent*. The end of all fruits is, of course, to secure the wide and favourable distribution of the seeds. In dry fruits this may be effected by the ripe fruit splitting open

with considerable force, and so scattering the seeds far and wide (spurge), or the walls of the dry fruit may simply yaw apart, and the (often hairy) seeds be exposed to the wind (cotton). Or the dry fruit may never split until the seed germinates and bursts it. Fruits that split when ripe, as in the former case, are called *dehiscent*; those that do not do so, *indehiscent*. Indehiscent fruits are often small, and spoken of in popular parlance as seeds—the fruit of the thistle (hairy for wind distribution), sunflower, and nasturtium, for instance. But where an indehiscent fruit contains a large seed with a considerable amount of food store therein, it is often protected against the misadventure of being eaten by a thick woody *pericarp*, as in the Barcelona nut. Succulent fruits, on the other hand, actually serve their purpose by being eaten. They present a pleasant tasting and often a conspicuous and attractive exterior, but the seed or seeds within are protected from digestion either by having the integument hard and impermeable, or by the inner layer of the pericarp subserving this protective function. In either case the seeds are distributed by the animal eating the fruit, after the passage of the alimentary canal, and sown thus under favourable conditions.

§ 92. Among Dry Indehiscent Fruits we may mention the *nut* with a woody pericarp, and the *achene* and *caryopsis* with a thin one. In the *achene* (Fig. IV. D, Sh. VII.) there is a space between the pericarp and the seed within; but in the *caryopsis* (Graminaceae, i.e., grain-bearers, grasses, etc.) the membranous pericarp adheres to the large seed (Fig. III., Sh. IX.). The achene is usually derived from a superior gynoecium, and commonly contains one seed. A hairy achene (as in the thistle) is called a *cypsela*. The *samara* is an achene which is winged, as in the elm, sycamore, and maple (Fig. VII., Sh. X.).

§ 93. Of Dry Dehiscent Fruits we may notice first those of one carpel. In the *follicle* (stonecrop) this splits along one edge (Fig. IV., Sh. X.), usually the margin of the carpel; in the *pod* (Legumenosae, pea, bean, etc.), along both the placenta and the opposite edge. The *lomentum*

(radish) is like a pod, but it is constricted between each seed, and breaks up into one-seeded joints.

§ 94. The *siliqua* and *silicula* are bicarpellary dry dehiscent fruits almost confined to the Cruciferae (wall-flower, e.g.). In the ovary of the wallflower we have two loculi separated by a false dissepiment (Fig. VII., Sh. VII.). The placentation is at the margins of the carpels. In the ripe siliqua the carpels separate like valves from the false dissepiment, to which, however, the placentae remain attached (Fig. C). The silicula (shepherd's-purse) is essentially similar. The two things differ in that the siliqua is longer than broad, the silicula as broad or broader than long. Other dehiscent fruits are called simply *capsules*, though the term capsule also covers pod, siliqua, and follicle. If capsules split along the midribs of the carpels, they are *loculicidal*; if the carpels part from the dissepiment or dissepiments, *septifragal*; if the dissepiments rupture, *septicidal*.

§ 95. A *schizocarp* is derived from a gynoecium, which splits up into separate *indehiscent* achenes (merocarps). This occurs in the mallow. The umbelliferae (epigynous, polypetalous flowers in umbels) have a bilocular ovary which splits in this way (Fig. 7, Sh. VIII.). The lomentum (§ 93) is, of course, a schizocarp.

§ 96. Coming now to **Succulent Fruits**, we may notice two chief types, the *drupe* and the *bacca*, or berry. The drupe has a pericarp usually of three very distinct layers,—the *rind*, or *epicarp*; the *pulp*, or *mesocarp*; and the *stone*, or *endocarp*, within which is the kernel or seed. The peach, cherry, or plum are examples. In the bacca there is an epicarp, but the whole inner pericarp is fleshy or pulpy, as in the gooseberry and cucumber: there is no stone. The orange is a superior berry.

§ 97. The student should notice the following true fruits or parts of true fruits, which might mislead him. The cocoa-nut, the walnut, and the almond are not nuts, but the endocarps (containing the seeds) of drupes. (All the edible

SHEET X.

1. (a) Inflorescence (*cyathium*) of the Spurge (Euphorbia). (a) its receptacle-like axis. *m. f.*, male flowers. *ped.*, peduncle of the female flower. *ov.* (b) a male flower. *st.*, the stamen. *ped.*, the peduncle, and *br.*, the bract. c., d., diagrams of the female and male flowers respectively.

2. A labiate flower, e.g., Horehound. A., flower from the side. B., corolla opened to show the didynamous and epipetalous stamens. C., the quadrilocular ovary and the style. D. (below), the diagram.

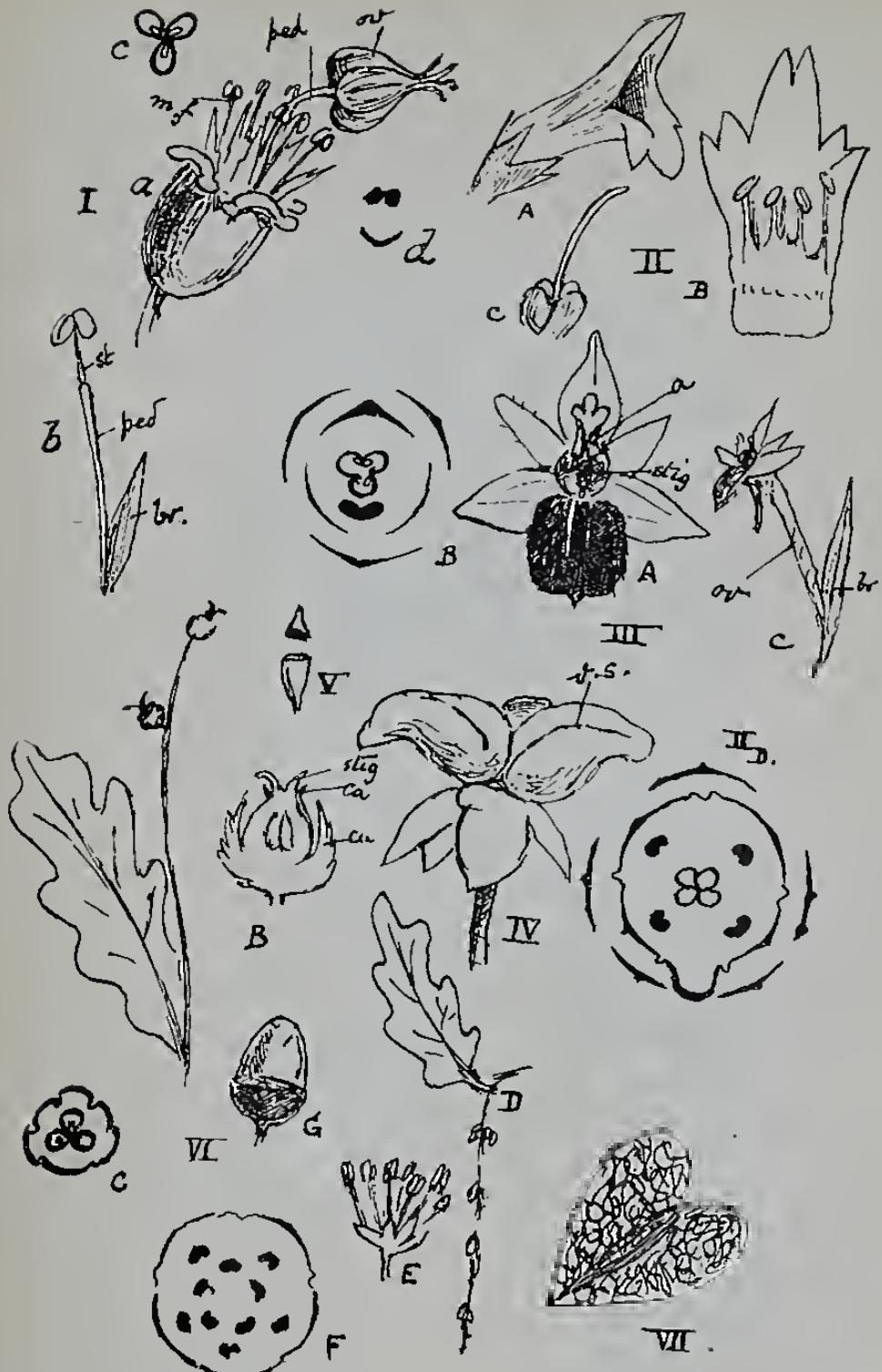
3. A., flower of the Bee Orchis. *a.*, one of the two anther lobes of the single stamen. *stg.*, the stigma. B., the floral diagram. C., flower from the side. Notice that the inferior ovary is twisted so that the anterior side of flower (stamen side) becomes actually posterior. Compare A. and B. .

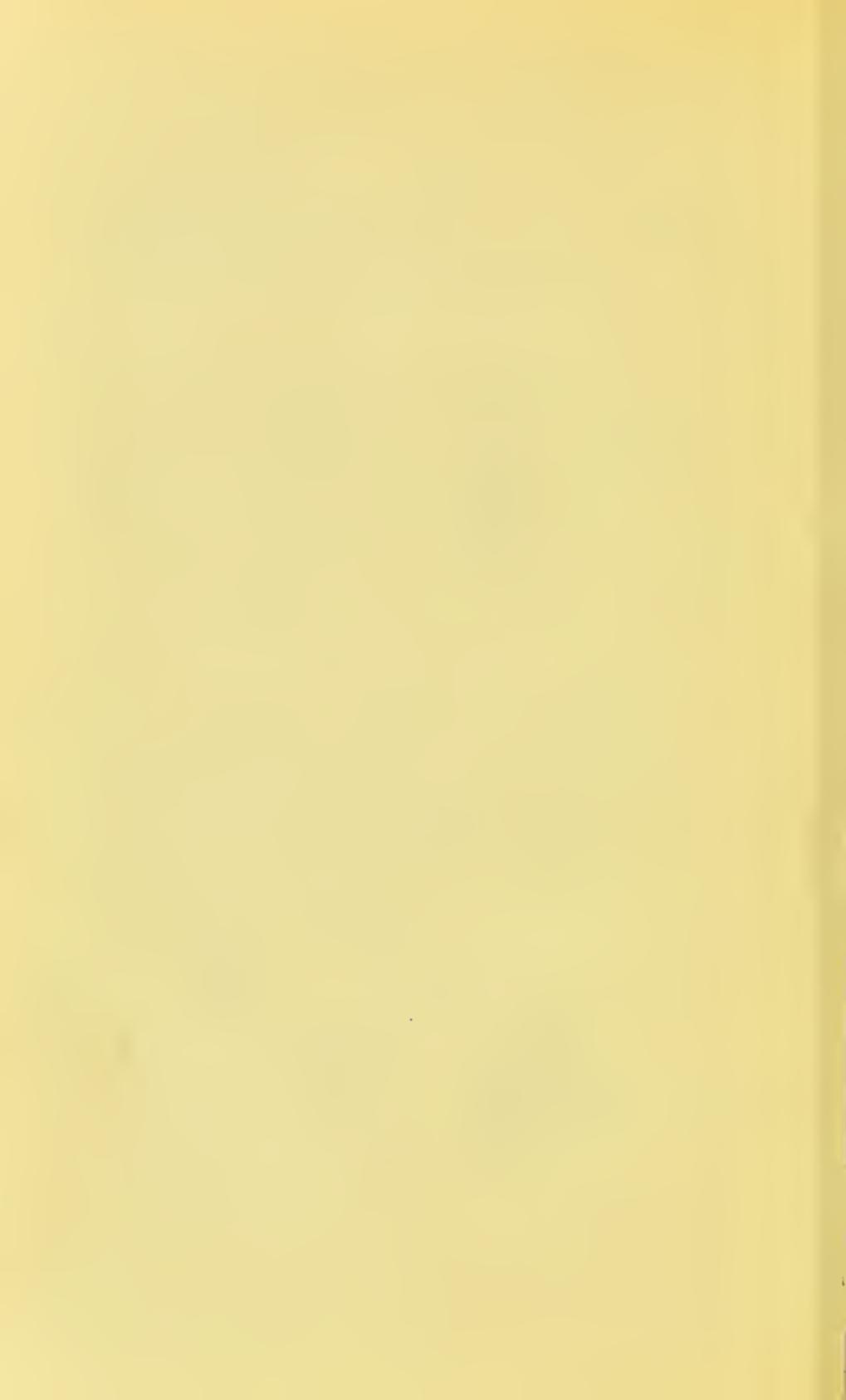
4. Follicles of paeony.

5. Pyxidium of plantain.

6. Oak. A.. Female inflorescence. B., Female flower with inferior trilocular ovary, superior stigma, *stig.*, and calyx. *ca.*, and with *cu.* a circular outgrowth from the peduncle. C., Diagram. D., E., F., Male catkin, single flower, and diagram. G., Fruit (the acorn) in its envelope derived from *cu.* in B. Two of the loculi of the gynoecium have aborted, one ovule of the two in the third loculus forms the seed.

7. Samara of the elm (winged achene).





part of the cocoa-nut is the seed : the endosperm is partly fleshy and partly milky.) The date-stone, again, is a seed having a very horny endosperm ; and the date itself, therefore, by the definition we have given, is a berry. Again, the brazil-nut is a seed from a drupaceous fruit. The ivy and holly "berries" are drupes. The banana is a berry degraded by cultivation and seedless. Loofah, that modern accessory of the bath, is the dried vascular skeleton of a melon-like berry. The drupe of the walnut is further noteworthy in being dehiscent ; the squirting cucumber is a dehiscent berry. The acorn, hazel, eating chestnut, and beech-nut are true nuts.

§ 98. Where we have an apocarpous gynaeceum, we have, as it were, numerous little fruitlets from the one flower. In such cases the whole fruit is called an etaerio of drupes, berries, achenes, as the case may be. When the flower is perigynous, and the deep receptacles surround the etaerio, we have a pseudocarp, styled a *cynarrhodium* (dog-rose). An apocarpous inferior gynaeceum does not, of course, occur. The blackberry and raspberry are etaerios of drupes, the buttercup an etaerio of achenes. The student must not confuse an etaerio (which is derived from a single flower) with the crowd of inferior achenes on a capitulum, each of which being derived from a single is, in itself, a fruit.

§ 99. **Pseudocarp** is a general term for structures having a deceptive resemblance to a true fruit, but in which other parts of the flower besides the gynaeceum persist. The *pome* (Fig. III., Sh. VIII.) simulates a drupe (compare peach and apple), and is typically represented by the apple or pear. Here the apocarpous gynaeceum of a perigynous flower becomes imbedded in the succulent receptacle. The "core" of the apple is the true fruit ; the fleshy part is not a mesocarp, but altogether outside the pericarp. The "*pome*" of the hawthorn having only one carpel, is still more like a drupe. In the strawberry the central core of the receptacle becomes succulent, and the true fruits are the little yellow pips, achenes, thereupon. The *sorosis* is an

entire inflorescence, of which the perianths of the individual flowers and the axis have become succulent, as in the pineapple and mulberry (*cp.* Fig. X., Sh. VIII.). The *sycconus* is the hollow inflorescence of the fig (§ 79) become succulent, and with the small true fruits, achenes, inside.

§ 100. But besides these special forms of pseudocarps it is not unusual to find structures outside the gynoecium persisting outside the fruit without any conspicuous coalescence therewith. The calyx often remains, for instance, as round the mignonette, and the bracts, as on the spiny head of the teasel. The *cupule* is a special investment round the fruit found in the oak (cup of acorn), the hazel (husk of nut), and their immediate relatives.

§ 101. The chief types of seed have already been fully dealt with in §§ 34, 35, 36.

IV.—*Pollen Grain and Ovule.*

§ 102. The two lobes of the anther of a flower plant consist at first of meristematic tissue. In each of the two lobes there arise two strands of cells, the *archesporia*, which are each surrounded by a special case of cells, the *tapetum*. As growth proceeds the cells of each archesporium frequently become separate one from the other and lie loose in the pollen sac. These cells are called *pollen mother cells*. The internal protoplasm of the mother cells divides into four masses, each of which forms itself a cell wall of its own, and becomes a **pollen grain**, and the cell wall of the mother cell becomes disorganised to liberate these. The anther lobe has beneath the epidermis a thickened fibrous layer, the *endothecium* (black in Fig. VII., Sh. XI.); and the unequal contraction of these two investments as the pollen ripens results in dehiscence.

§ 103. The pollen grain is at first a single cell (Fig. IX. a, Sh. XI.). It has two coats, the *intine* (*in.*) and the *extine* (*ex.*). The extine may be sticky, and sculptured in entomophilous cases, or inflated by gas vesicles in anemophilous. The extine is often weak at one or two points to facilitate the extrusion of the pollen tube, to be presently described.

§ 104. Before pollination occurs the **pollen-grain nucleus** divides into two parts, a smaller and a greater; the smaller is called the *vegetative nucleus* (*v.c.*), and the larger the *reproductive nucleus* (Fig. IX. b). In the flowering plant (Angiosperm) the cell division is only in very few cases completed by the formation of a cell wall between vegetative and reproductive nuclei; but in the pollen of the pine this occurs. The vegetative nucleus takes no part in the reproductive process. The pollen is now transferred to the stigma, the sticky secretion of which acts as a stimulant and as

nutriment to the grain. This proceeds to grow much as if it were a parasitic organism. The extine is ruptured (Fig. IX. c); the intine grows out as a root-like process, and pushes its way down the style. The reproductive nucleus shifts into this pollen tube and keeps near the end of it as it grows down to the ovary. Finally, the tube grows into the micropyle of the ovule. There we will leave it for the present, while we consider the structure of the latter.

§ 105. The young ovule (Fig. I., Sh. XI.) consists of a mass of parenchyma, the *nucellus*. This is surrounded by one or two integuments. The integuments are incomplete at a point called the *micropyle*. The ovule has a stalk, the *funiculus*. Usually the nucellus is bent sharply back on the funiculus, and the ovule is then called *anatropous*; but sometimes nucellus and funiculus are in the same straight line (*orthotropous*), or the nucellus is bent at the middle (*campylotropous*). Within the nucellus is a single cell, the *archesporium*, or *embryo-sac mother cell*, which divides repeatedly, one of the resultant cells finally enlarging to form what is called the *embryo sac*.

§ 106. The embryo sac is therefore at first a single cell. But it undergoes endogenous* division, and becomes greatly enlarged, feeding the while in a parasitic manner at the expense of the nucellus in which it is embedded. Its original nucleus divides into two, these two into four, and the four to eight; four of these nuclei are at one end of the sac, and four at the other. From either end one nucleus moves to the centre, and the two coalesce. The three nuclei at one end form cell walls round themselves.

§ 107. The embryo sac after this division (Fig. II., Sh. XI.) lies close to the micropyle, and contains three cells with cell walls, and four nuclei (one lying at the

* Division *within* the parental cell wall. In ordinary cell division five of the six walls of the resultant cell were parts of the wall of the parent; but in endogenous division, such as occurs here and in the pollen mother cells, the young cells form complete cell walls within that of the parent.

centre) without. The central nucleus formed by the coalescence of two is called the secondary *embryo-sac nucleus* (*emb.n.*). The three cells with cell walls are at the end of the embryo sac remote from the micropyle, and are called the *antipodal cells* (*ant.*). Two of the nuclei, the *synergidae*, lie surrounded by protoplasm close to the micropyle; and immediately below them comes the third, the *ovum* (*oo.*), or *oosphere*, the female reproductive cell, which at present has no cell wall. Its nucleus is the female pro-nucleus.

§ 108. We left the reproductive nucleus, or male pro-nucleus, in the pollen tube at the micropyle. The tube forces its way through the nucellus into immediate contact with the embryo sac. The direct passage of the reproductive nucleus from the tube to the female pronucleus has never been observed. It disappears from the pollen tube, however, and shortly after an additional nucleus appears in the ovum; the two move towards each other, and coalesce to form a *first segmentation nucleus*. The synergidae appear to assist the passage of the male nucleus. The ovum forms for itself a cell wall, and proceeds to divide to form the embryo, the future plant. The fertilised ovum is spoken of as the *oospore*. The whole of the oospore does not form the embryo; it cuts off first a *basal cell*, which becomes attached to the embryo-sac wall, and then a string of cells, the *suspensor*, the development of which pushes the rest of the dividing oospore (*embryonal mass*) into the middle of the embryo sac. This embryonal mass at the end of the suspensor continually divides, and radicle, plumule, and cotyledons or cotyledon become apparent. Simultaneously with these developments the adjacent parts are awakened into a sympathetic activity of growth and change. The synergidae and antipodal cells disappear; the secondary nucleus divides repeatedly, usually by free-cell formation, and forms a mass of food-stored parenchyma, the *endosperm* (Figs. III. and IV.); the embryo sac usually grows so as to fill up the entire space occupied by the nucellus; the integuments of the ovule become the seed coat; and the carpels proceed to develop into the pericarp of the fruit.

The embryo may continue to grow and absorb the endosperm, as in exalbuminous seeds; or it may remain small, as in albuminous seeds (*cp. §§ 34, 36*). In rare cases a part of the nucellus has material stored in it, and remains in the seed as the *perisperm*.

§ 109. The seed undergoes a longer or shorter resting stage, and then, with suitable moisture, warmth, air, and, later, nourishment, develops by a simple process of growth into the plant (= **germination**).

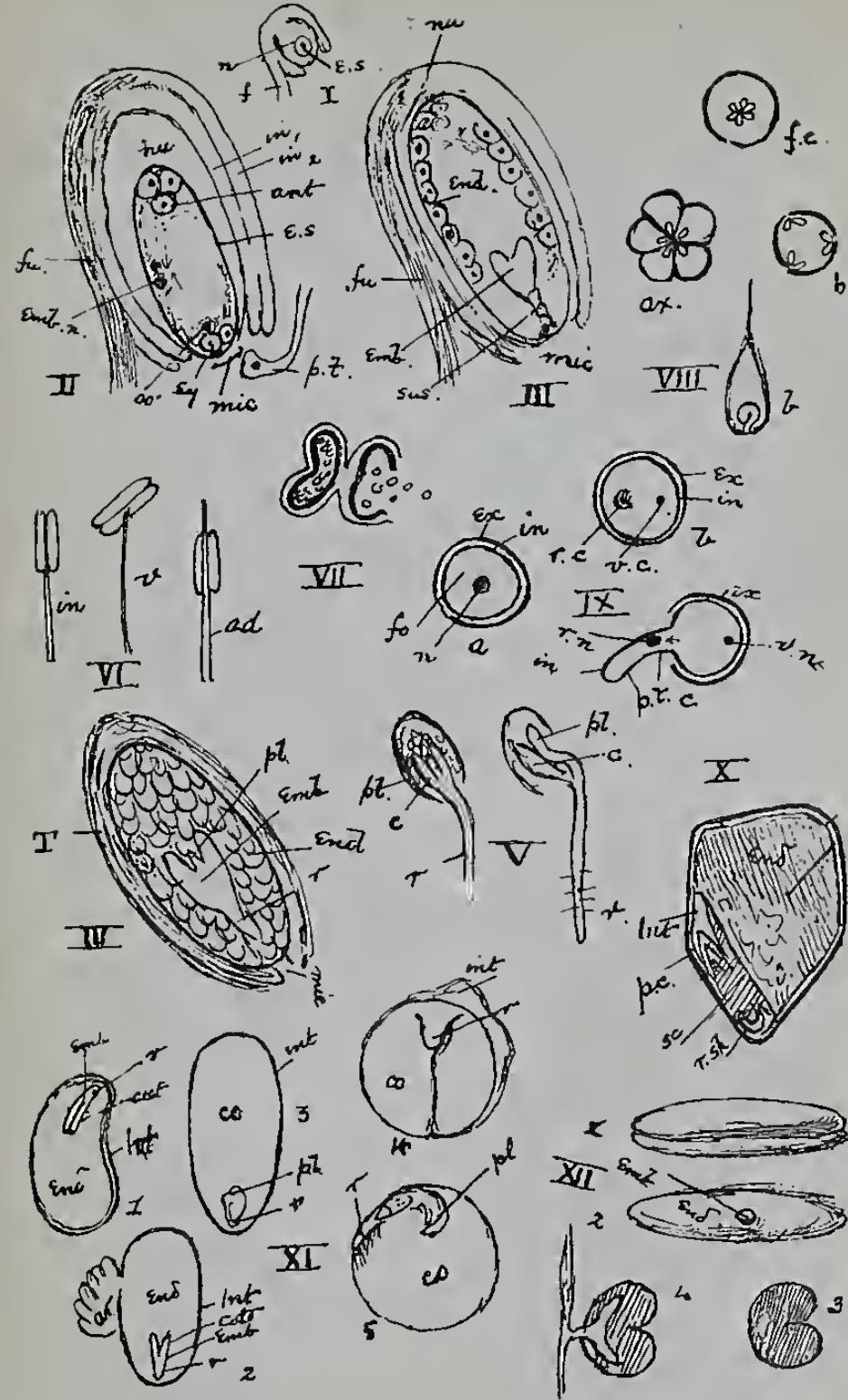
§ 110. We would particularly call the student's attention to this: that the pollen grain and the ovule are *not* the actual sexual elements in the reproductive process, but the reproductive nucleus of the pollen grain and the ovum. We may perhaps tabulate what we have described in this form, to render this point clearer.

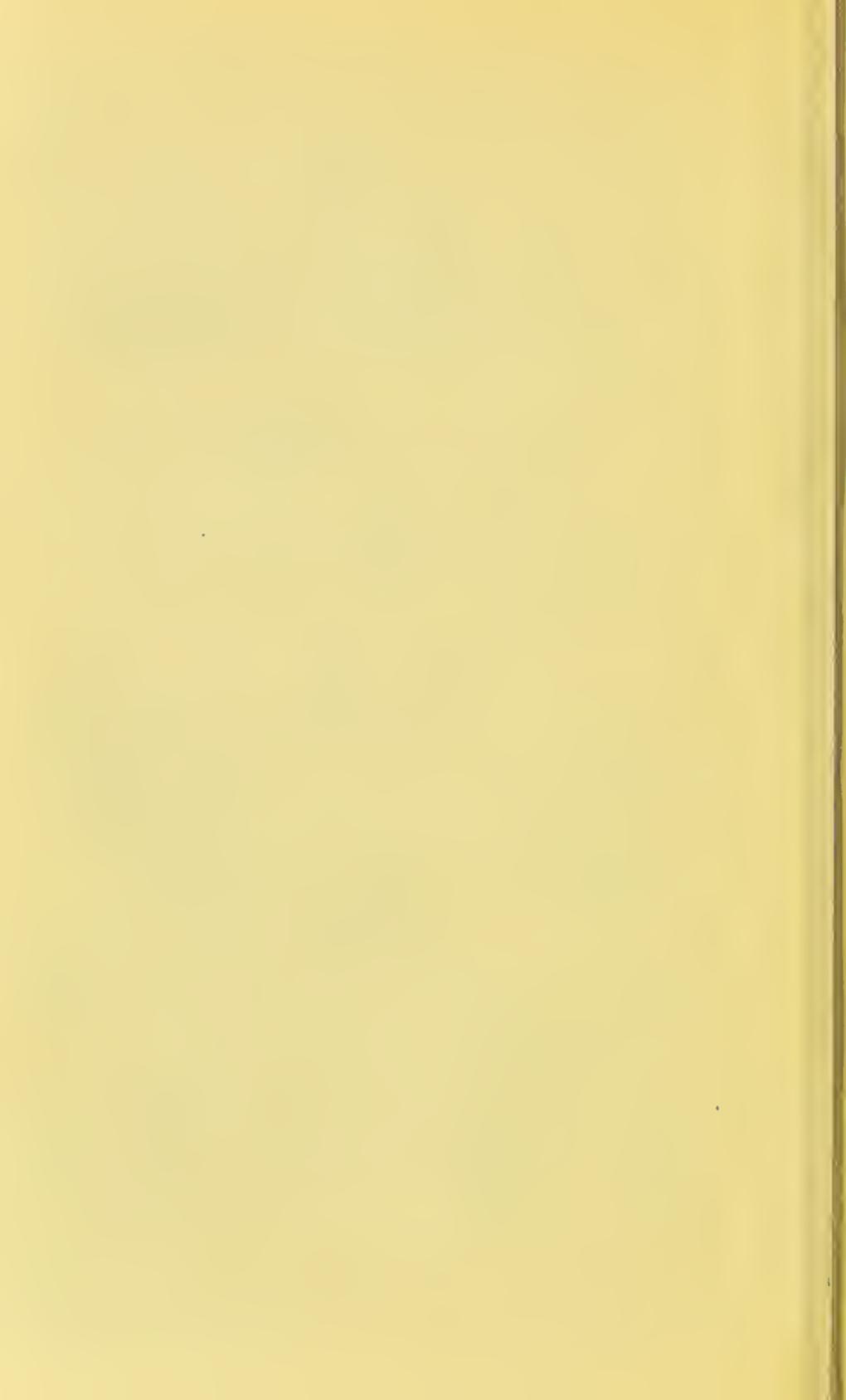
(1) Pollen sacs contain Archesporium (string of cells), from which are developed <i>pollen grains</i> ,	Ovule contains Archesporium (single cell), from which is developed <i>embryo sac</i> ,
(2) which grow and divide into vegetative and	which grows and divides into antipodal cells, embryo- sac nucleus, synergidae, and
(3) reproductive nucleus.	ovum.
	(4) FERTILISATION. Basal cell, suspensor, embryo.
	 (5) Adult plant.

[The numbers are simply to facilitate comparison with the similar tables for the fern and pine.]

SHEET XI.

1. Immature ovule. *n.*, nucellus. *e. s.*, embryo sac. *f.*, funicle.
2. Mature ovule ready to be "fertilized" by pollen tube, *p. t.* Evidently a dicotyledon, since two integuments, *in*₁ and *in*₂, are shown. *mic.*, the micropyle. *nu.*, nucellus. *ant.*, antipodal cells. *sy.*, synergidae. *oo.* the (wall-less) oosphere. *emb. n.*, the embryo sac nucelns just being formed by the coalescence of two. *fu.*, funiculus.
3. The same after fertilization. *end.*, the endosperm forming from *emb. n.* in 2 by "free cell formation." *emb.*, the embryo on its suspensor, *sns.*
4. Seed (quite diagrammatic). *T.*, the testa (seed coat). *end.*, endosperm. *pl.*, plumule of embryo, between the cotyledons. *r.*, the radicle.
5. Diagrams of the germination of 4.
6. Innate (*in.*), adnate (*ad.*), and versatile (*v.*) anthers.
7. Cross section of ripe anther.
8. Free central, *f. c.*, axile, *ax.*, parietal, *p.*, and basal, *b.*, placentation.
9. Pollen grain (a) and (b) before pollination, (c) with pollen tube (*p. t.*) extruded to perforate style. *ex.*, exine. *in.*, intine. *fo.*, fiovilla. *r. c.*, reproductive nucleus. *v. n.*, vegetable nucleus.
10. Fruit (*caryopsis*) of maize. *p. c.*, pericarp. *int.*, testa. *sc.*, scutellum. *r. sh.*, root sheath. Compare Sheet IX., 3, b.
11. Actual seeds of (1) Poppy, (2) Celandine, (3) Barcelona or Filbert nut, (4) Pea. (5) the latter, with one cotyledon removed.
12. Datestone. 3, in median section. 4, germinating.





THE SCOTCH FIR.

§ 111. The Scotch fir (*Pinus sylvestris*) approximates most closely to the arborescent Monochlamydeous Dicotyledons among Angiosperms in its structure. It differs from them most strikingly in its floral organs. These, instead of being arranged upon a flattened receptacle, are upon an axis elongated like an ordinary vegetative shoot, and the ovules are not enclosed in an ovary, but exposed. It is this difference that places the pine outside the group of flowering plants, as the phrase is used in its narrower sense (=Angiosperms), and among the Gymnosperms. In common with the Angiosperms, however, it has collateral vascular bundles, and forms true seeds, and the character of its reproductive process clearly marks it off from the vascular Cryptogams. (Compare *infra*, § 135.)

§ 112. The stem of *Pinus* undergoes secondary thickening after the fashion of a woody dicotyledon. There are certain special features, however, to be observed. The stem is highly resinous, and numerous schizogenous resin passages occur in cortex and xylem; this, however, is not a systematic distinction from the Dicotyledons, among which these canals also occur. The character of the thickening of the xylem elements is peculiar. They are pitted, but at the pits the lignified thickening separates from the proper wall of the cell, and arches inwards to cut off a small chamber from the main space of the fibre. The aperture between this side chamber and the general cavity is circular. Looked at in section with the high power these bordered pits have the appearance seen in Fig. XV. *a*, Sh. XII.; seen in face they appear as in Fig. XV. *b*, Sh. XII. They occur almost invariably on the radial longitudinal walls. We may also notice that true vessels are altogether absent

from the secondary xylem. The whole of the secondary xylem consists uniformly of fibres, thickened as above described and spoken of as *tracheides*, through which run resin passages and medullary rays.

§ 113. The branching of the stem is monopodial (§ 50) and after the racemose (§ 78) fashion. A diagram of the arrangement of leaves and branches as they would appear in autumn on a vegetative branch is given in Fig. IV., Sh. XII. *a* to *b* is the growth of the main stem for the current year. It terminates of course in the bud (*b.t.*), which will expand to continue it next spring. Around the stem in a close spiral are arranged scale leaves (*s.l.*), in the axils of each of which, on the younger growths, is a short branch stem, *a shoot of limited growth* (*s.l.g.*), leaving at its end two green needle-like (= *acicular*) foliage leaves. Immediately around the terminal bud of unlimited growth (*b.t.*) these shoots of limited growth are replaced by *lateral buds of unlimited growth* (*b.l.*), which will expand into branches next spring. The whole of the system *A.* to *B.* was represented in the early spring by a bud at *B.* *l.br.*, *l.br.*, which are now branch shoots of unlimited growth resembling *A.* *B.*, were then lateral buds around *B.* From *B.* downward is evidently the growth of the previous year, and its xylem in cross section would show one complete annual ring and another almost completed. The buds *b.l.* and the branches *l.br.* appear to be arranged in whorls, but really their arrangement is a close flattened spiral (= *pseudo-whorl*).

§ 114. The foliage leaves are "centric" (§ 31). One is figured in transverse section in Fig. XIII., Sh. XII. Two vascular bundles run the length of the leaf surrounded by *colourless parenchyma (pericycle)*. Around this is a very distinct bundle sheath, and without this again the chlorophyllaceous *mesophyll*, the cell walls of which are thickened and project internally in a characteristic manner. Immediately beneath the thick epidermis is the *hypodermis (hy.)* of thickened cells. Resin passages (*r.p.*) run through the mesophyll. Stomata are small and few and far between. Obviously

the amount of evaporation from such a leaf as this must be much less than from the thin expanded leaves of the ordinary dicotyledon, and it is in connection with this fact that the relative absence of root hairs becomes explicable.

§ 115. The root of the Scotch fir is very similar to that of a typical dicotyledon. The pericambium originates cork and cuts off the cortex in the usual way.

§ 116. The stamens are arranged upon short deciduous shoots, the **male cones**, which appear in the place of shoots of limited growth (Figs. I., II., and III.). They are to be looked for in May. They are scale-like leaves, and have on the under side two pollen sacs instead of four, as in Angiosperms. There is an *archesporium* (here at first a single cell), and the pollen mother cells divide in the typical endogenous manner into four grains. The grains are small, very abundant, and with two large air chambers, spaces where the extine is separated from the intine by gas, and indicative of the anemophilous pollination of this type. They undergo *complete internal division* into two *cells*, the *reproductive* and *vegetative* cells, before they are shed in May. The latter may subdivide again. (Compare §§ 103 and 104.)

§ 117. The **female cone** (Fig. V.), on the other hand, takes the place of a shoot of unlimited growth. This bears small scale leaves, from the upper surface of which grow the enormous *ovuliferous scales*. On these are the orthotropous ovules, which have a nucellus and a single integument, produced at the micropyle to form a *micropylar canal*. There is a one-celled *archesporium* which divides off an *embryo-sac mother cell* which subdivides. One of the resultant cells becomes the *embryo sac*. (Compare § 105.)

§ 118. In the young green cones that the student will meet with in May the pollen is upon the micropyle, and the embryo sac is small and deep in the nucellus. A pollen tube grows out from the *reproductive* cell, rupturing the extine in the usual way, and bores a little way into the nucellus, and then becomes quiescent for almost a year.

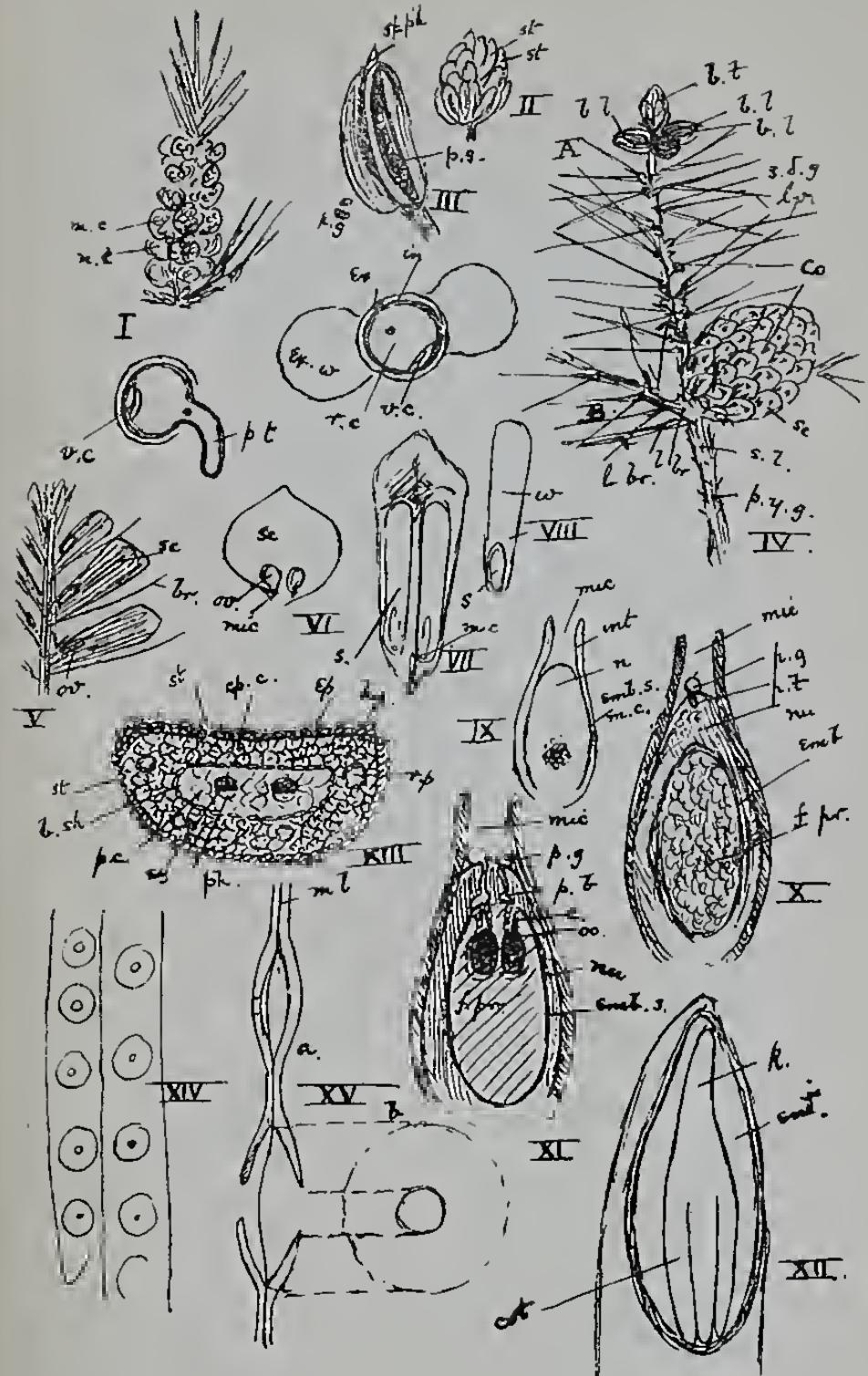
§ 119. In this interval the cone grows large and becomes brown. The **embryo sac** also undergoes extensive modification, gradually occupying almost the whole of the nucellus. Instead of the three antipodal cells, nucleus, and egg apparatus of the Angiosperm, a great mass of parenchymatous tissue arises. This is called the *endosperm*, though it obviously differs from the similarly named tissue of the Angiosperm in being formed before fertilisation. In this appear certain bodies which used to be called *corpuscula*, but to which the name of *archegonia* is commonly given now, since their substantial identity with the female organs, the archegonia, of ferns is now beyond dispute. These archegonia (Fig. 11, Sh. XII.), consist of a *neck* made up of several cells (neck cells) with a central canal through them, an *ovum*, and a small cell, the *ventral canal cell*, lying in the canal and cut off from the ovum before fertilisation.*

§ 120. After a year's rest the pollen tubes resume growth, and thrust their way into the canals of the archegonia. The nucleus of the reproductive cell (male pronucleus) passes to the ovum, and fuses with the female pronucleus to form the *first segmentation nucleus* (= germ nucleus), which proceeds to segment. Four basal cells and suspensors are formed from each oospore, and there is at first a number of embryos growing down into the endosperm, and competing for nourishment (*poly-embryony*). But one more vigorous than the others obtains the major share of the nourishment, and the growth of the rest is stopped. The integument becomes the *testa*, and it is produced into a thin wing. Finally very little of the nucellus remains, and the dominant embryo lies in the endosperm and has numerous cotyledons. Before these changes are accomplished another year has passed. The scales of the ripe cone, when it has fallen upon the ground, yaw apart, and the seeds are then exposed to the wind and scattered far and wide to take their chance of a favourable resting-place.

* Compare the "polar bodies" in zoology. See "Biology," Part I., Development of Frog.

SHEET XII.

1. Shoot-bearing male cones (*m. c.*, *m. c.*) of *Pinus sylvestris*.
2. A male cone. *St.*, the stamens (=male sporophylls).
3. A male sporophyll (stamen). *p. s.*, the pollen sac. Below it are pollen grains enlarged, showing the wings of the extine, *ex. w.*, and the division of the forilla into separate reproductive vegetative cells, *r. c.* and *v. c.* Compare Sheet XI., Fig. 9.
4. Shoot of *Pinus* in spring. *b. t.*, terminal bud. *b. l.*, lateral buds of unlimited growth. *A.B.*, growth of previous year still bearing *s. d. g.* shoots of definite growth, each of which carries two acicular leaves (*l. v.*). In the previous spring *b. t.* was at *B.* and *l. br.*, the lateral branches were lateral buds. *p. y. g.* is the previous year's growth. *Co.* is a female cone with its *sc.*, scales, replacing an ordinary lateral bud of indefinite growth. The male cones replace shoots of definite growth.
5. Scale of immature cone (summer), showing ovules and micropyle.
6. Scale of second-year cone with seed, *s.*
7. A seed.
8. Spring ovule. *Emb.*, *s.*, *m. c.*, embryo sac mother cell.
9. Summer ovule.
10. Autumn ovule. *c.*, canal. *f. pr.*, endosperm. *ar.*, archegonia. Rest of lettering as in Sheet XI.
11. Ovule of second summer, *i.e.*, seed. *R.*, radicle.
12. Transverse section of a leaf. *hy.*, hypodermis. *r. p.*, resin passages. *ep. c.*, mesophyll. *b. sh.*, bundle sheath. *p. c.*, pericycle.
13. Bordered pits (from the radial wall of tracheides).
14. Diagram of bordered pit.



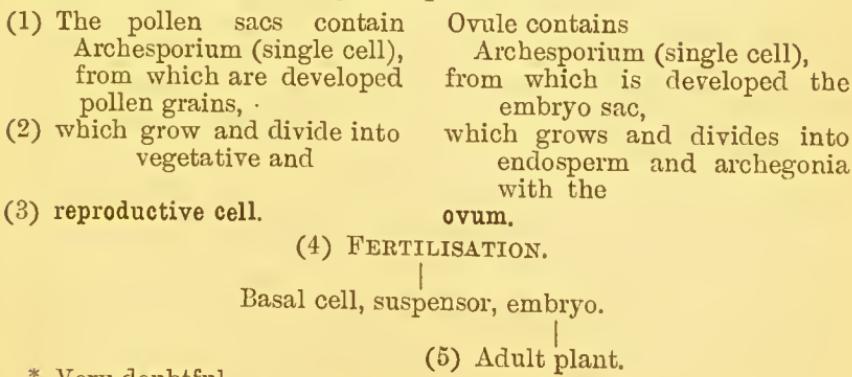


§ 121. The cotyledons of the pine are *epigeal*. They are remarkable in forming chlorophyll while still underground in the dark, a most exceptional thing. Commonly light seems absolutely necessary to the development of this colouring matter, and when normally green plants are grown in the dark they are bleached (= *etiolation*).

§ 122. We may perhaps summarise the differences of Gymnosperm and Angiosperm that we have brought to light in this chapter. The pine has,—

1. Cones with *elongated axis*, not true flowers with a flattened *receptacle*.
2. Two pollen sacs, not four.
3. Ovules naked—no ovary.
4. Hence there is no true fruit.
5. Pollen grains—division is completed by cell walls.
6. The embryo sac in the Gymnosperm is deep in the nucellus, in the Angiosperm it projects at the micropyle, and has either no covering of nucellus or a very thin one.
7. Endosperm of Gymnosperm = ? antipodal cells of Angiosperm (+ secondary nucleus ?)*
8. The ovum of Gymnosperm has a cell wall.†
9. Polyembryony rarely occurs in Angiosperms.
10. Numerous cotyledons in the Gymnosperm.

§ 123. We may also repeat here the life cycle table we have already given for the Angiosperm in the allied form it would have for the Gymnosperm.



* Very doubtful.

† The Casuarineae (Dicotyledons) have a cell wall round the ovum.

THE BRACKEN FERN AND ITS LIFE HISTORY.

§ 124. The bracken fern is our type of the Vascular Cryptogams (§ 42). It has no flowers and no ovulé-like structures. It therefore forms no seed. Leaves which scarcely differ at all from the ordinary foliage leaves bear on their under sides groups of "sporangia," small cases in which are formed *spores*. These spores give rise to small green and quite independent plants, altogether unlike the parent, and called *prothallia*. These bear the sexual organs, from which are produced the familiar frond-bearing plants again. The frond-bearing, spore-producing plant is commonly spoken of as the *sporophore* (= *sporophyte*) generation; the prothallium, as the *oophore* (= *gametophyte*, *oophyte*). This alternation of sporophore with oophore is spoken of as **alternation of generations**. It occurs in all vascular cryptogams. The sporophore, we shall see as we go on, answers to the *plant* of the phanerogam, and we will therefore describe its chief features first.

§ 125. In the bracken fern the stem of this is a *rhizome* (§ 38), throwing up one very large and greatly divided leaf, the *frond*, yearly. It is covered, especially at the node, with reddish hairs. The vascular bundles are not *collateral*, but *concentric* (§ 42). Besides the vascular bundles, tracts of prosenchyma, with a very characteristic brown thickening (*sclerenchyma*), play an important part in the stem. These elements are arranged in the following way (Fig. 2, Sh. XIII.). Externally there is an epidermis, and beneath this a continuous layer of sclerenchyma; then comes a zone of small vascular bundles, two great patches of sclerenchyma forming an incomplete ring, and then large vascular bundles (usually two). The bundles are elliptical in shape.

Each has a bundle sheath, within which is a phloem sheath (=pericycle), proto-phloem, phloem, and then the xylem, which consists chiefly of *tracheïdes*, large parenchymatous cells with bordered pits.* Here, however, the pits, instead of being circular, are considerably drawn out, so that the fibres (Fig. 5, Sh. XIII.), have a ladder-like appearance (=scalariform thickening). The sieve tubes have sieve plates on their lateral walls. At the focus of the elliptical outline of each bundle is a group of small first formed cells, the *protoxylem*. The growing point of stem and root alike is not simply a featureless mass of meristem. There is one distinct *apical* cell from which all the mass of the plant body is derived.

§ 126. The leaves are repeatedly pinnate. The venation is *furcate* (§ 29). They also differ from the foliage leaves of flower plants in bearing the sporangia to be presently described.

§ 127. The roots are adventitious (§ 52). They are not very dissimilar to those of phanerogams; but there is one central concentric bundle, and the branches arise from the endodermis. The most striking difference is that already noted in the growing point. The inner part of the cortex is sclerenchymatous. There is no secondary thickening or cutting off of the bark by cork.

§ 128. The sporangia are collected in groups called *sori* on the under side of the veins. They are epidermal outgrowths, that is, essentially trichomes. Each (Fig. 3, Sh. XIII.), consists of a stalk and a lens-shaped *capsule*. Around the edge of this capsule runs a band of specially thickened cells, the *annulus*, incomplete at one point. Amid the sporangia are sterile infertile hairs, the *paraphyses*. In the male fern, but not in the bracken, the group of sporangia forming each sorus is covered over by a special roof, the *indusium*. The ripe sporangium is full of spores, and on drying the unequal contraction of

* The bordered pits at the end of the tracheïdes are perforated in pteris, and they are therefore often called vessels.

the annulus and the rest of the capsule causes rupture at the point where the former is imperfect, and it straightens out, jerking the spores to some distance.

§ 129. The spores originate from spore-mother cells. The *archesporium* is at first a single cell in the capsule. By repeated divisions it gives rise to certain *tapetal cells*, and to the spore-mother cells. These, it is noteworthy, divide endogenously into four, precisely after the manner of division of the pollen-mother cells in all phanerogams. The spores also resemble pollen grains in having two coats, called here the *exo-* and *endosporium*. The *exosporium* of the liberated spore bursts, and the *endosporium* grows out.

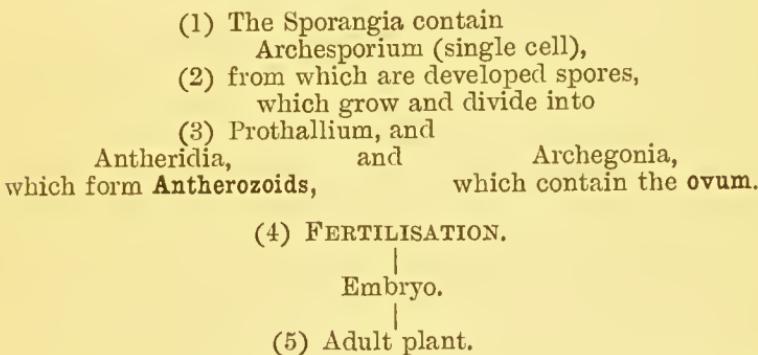
§ 130. The developing prothallium (*oophore*) is at first a multicellular filament, but it speedily broadens out to form a heart-shaped expansion (Fig. XI., Sh. XIII.), one cell thick at the edges, but thicker at the centre (*cushion*). It sends out *rhizoids* or root hairs from its lower edge, and its cells develop chlorophyll. By these it absorbs, assimilates, transpires, and grows as a perfect independent plant. The male organs or *antheridia* appear among the root hairs, the female organs or *archegonia* only on the cushion.

§ 131. The antheridium (Fig. XII., Sh. XIII.) consists of wall and lid cells and of a central cell. This central cell divides up into *spermatocytes* or antherozoid mother cells. The absorption of water by the antheridium leads to its bursting, and the spermatocytes escape. They presently release their nuclei, which form the mass of the antherozoids. An *antherozoid* or *spermatozoid* consists of naked protoplasm, a spirally coiled head or nucleus terminated by cilia. It has a general resemblance to the spermatozoid of an animal (*vide* "Animal Biology"), and is exceptional among vegetable cells in having no cellulose cell wall.

§ 132. The neck of the archegonium (Fig. XIII.) pro-

jects from the prothallium, but otherwise it has the general resemblance to the archegonium of the pine. It has neck cells, ovum, canal cell, and a ventral canal cell. The latter two undergo degeneration into mucilage, and swelling up, open a path for the antherozoids. The head of one of these (male pronucleus) fuses with the ovum nucleus (female pronucleus). The ovum then divides continuously to form an embryo, which by a simple process of growth becomes the sporophore again.

§ 133. We may represent this life history of the fern by a table similar to those we have given for flowering plant and pinus.



§ 134. Now we shall be able to collate these successive stages of this life circle with that of the flowering plant most clearly by briefly mentioning what occurs in the case of *Equisetum* (the common field horsetail) and *Selaginella*, a hothouse plant which has no popular name known to me. The form of their vegetative organs need not concern us. They are both vascular cryptogams having the usual alternation of generations and motile antherozoids.

§ 135. *Equisetum* forms spores just as the fern does, but the resultant prothallia are of two kinds. Either they are small (male prothallia) and bear only antheridia, or large (female prothallia), and bear only archegonia.

Hence we may represent the life history of *Equisetum* in a table thus :—(1) The Sporangia contain

Archesporium (single cell),

(2) from which are developed spores,
which grow and divide either into

Male Prothallia

or

Female Prothallia,

which bear Antheridia,

which bear Archegonia with the

(3) forming **Antherozoids**.

ovum.

(4) FERTILISATION.

|
Embryo.

(5) Adult plant (Sporophyte).

Here the sexual difference has worked back, as it were, towards the asexual generation, and affects the asexually developed prothallia (oophyte).

§ 136. In *Selaginella* this difference has reached back still further and affected the spores and the sporangia. The young sporangia are all pretty much alike, but as they develop some become *microsporangia* and develop only small spores (= *microspores*), destined to form male prothallia, while others are *macrosporangia* and develop *macrospores*, forming the female oophytes. Neither male nor female prothallia are very large, but both are detached from the parent. The male prothallium consists of two cells, one of which becomes an antheridium and forms antherozoids. The developing ovum cuts off a suspensor in exactly the same way as the ovum of the phanerogam. The entire life history, briefly indicated, runs thus :—

(1) Microsporangia form

Archesporium (one cell),
from which are developed
Microspores,

(2) which grow and divide to
form (unicellular) Male
Prothallia,

(3) which bear each an An-
theridium, forming
Antherozoids.

Macrosporangia form

Archesporium (one cell),
from which are developed
Macrospores,

which grow and divide to form
Female Prothallia,

which bear Archegonia with
the
ovum.

(4) FERTILISATION.

|
Suspensor and Embryo.

(5) Adult plant.

SHEET XIII.

1. Rhizome (*rh.*) of *Pteris*. *fr.*, the Frond. *b.*, bud of next year's frond. *p. y.*, vestige of the last year's frond. Each leaf has a stem bud at the base

2. Gross section of rhizome. *i.* and *e. sc.*, inner and outer sclerenchyma. *o.* and *i. b.*, outer and inner vascular bundles. *f. t.*, fundamental tissue.

3. Cross section of some erect fern stem, e.g., male fern (*Aspidium*).

4. A single bundle. *b. s.*, bundle sheath. *p. s.*, phloem sheath or pericycle (large cells with starch). *p. ph.*, protophloem smaller cells. *ph.*, phloem. *xy.* *v.*, xylem tracheides. *pxy.*, protoxylem (first formed from the procambium strands).

5. Scalariform pits.

6. Growing point with *single apical cell*.

7. A sorus in section (the male fern has an *indusium*, like a parasol covering this). *sp.*, the sporangia. *v.*, a vein.

8. Sorus of *Aspidium*, the indusium removed.

9. Sporangia. *a.*, unbroken. *b.*, ruptured. *an.*, the annulus. *lo.*, a spore enlarged.

10. Spore germinating.

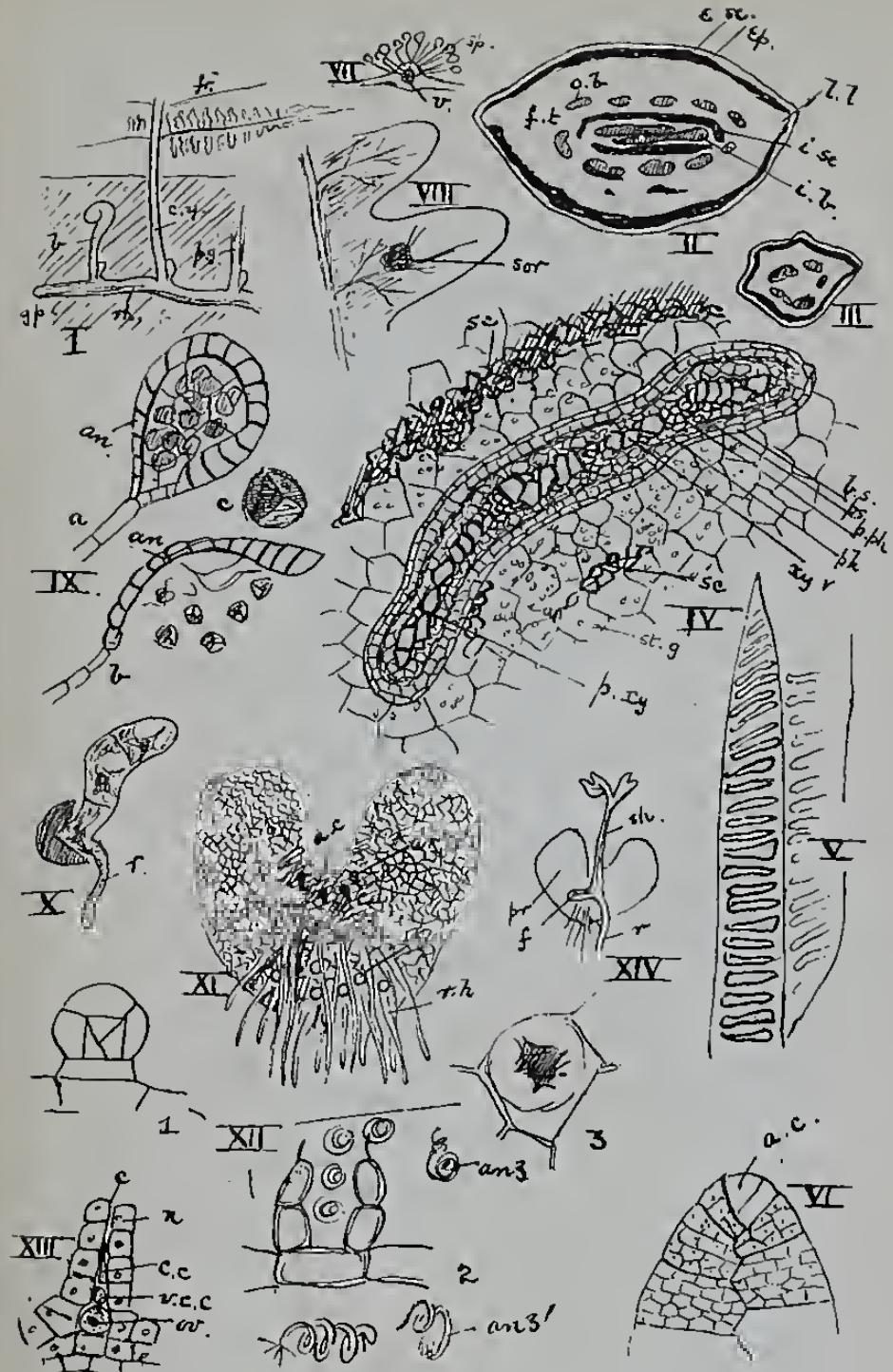
11. The prothallus. *a. c.*, position of apical cell. *cu.*, the cushion. *ar.*, archegonia. *an.*, antheridium.

12. Antheridium. 1, immature; 2, dehiscing to liberate the antherozoids. *anz.*; 3, empty.

13. Archegonium with its neck, *n.*, canal, *c.*, canal cell, *v. c. c.*, ventral canal cell, *r. c. c.*, and ovum *ov.*

14. Development of embryo. *f.*, the foot absorbing nourishment from prothallus.

To face page 72.



§ 137. Now, it will not be hard for the student to pass from this life circle to that of the pine, and from that to the flowering plant (§§ 110, 123). He will realise then that in these **phanerogams** we really have an alternation of generations, *disguised by the great reduction of the once free oophore generation*. The pollen grain is evidently no sexual conjugating cell, but a *microspore*. It is developed just like the fern spore by the endogenous division of a mother cell (derived from an *archesporium*), and like a spore it is released to have an independent growth of its own. But in the Phanerogam it falls not upon the ground, but upon a stigma (Angiosperm) or micropyle (Gymnosperm), and grows without chlorophyll in a parasitic manner. The vegetative cell of the phanerogam is evidently the male prothallium ; the pollen sac is the *microsporangium*. The ovule again is the *macrosporangium*, and the embryo sac *before it divides* is the macrospore. In the pine the archesporium does actually separate off a cell, the embryo-sac mother cell, which divides endogenously after the manner typical of spore-mother cells. One of the resultant cells becomes the embryo sac, which in the pine proceeds to follow out its development in an evidently typical way. The endosperm of the pine is obviously a female prothallium, and about the identity of its corpuscula with archegonia there can be no shadow of doubt. From this we may infer that the antipodal cells of the flowering plant are the vestiges of the dwindling female prothallium. An important point to notice, however, is that the *male prothallium* forms no antherozoids ; the pollen-tube nucleus corresponds to the original nucleus of the antheridium, but it never subdivides. The necessity for motile elements is of course obviated by the quasi-parasitic development of pollen grain and embryo sac close together ; and so in the gradual evolution of the flowering plants this particular stage has been at last abbreviated to nothing.

§ 138. In those cryptogams where the macrospores are shed to develop there can evidently be no seed. The seed is essentially the result of the parasitic adherence of the macrospore to the parent. It is the entire result of the development of the macrospore *plus* the macrosporangium,

from which this was never liberated. Hence phanerogams are often called *seed plants*, and cryptogams in distinction *spore plants*.

§ 139. In "Biology," Part I., it was shown how the rabbit, frog, dog-fish, and amphioxus were probably descended from a common ancestral form. The family likeness in their anatomy was reinforced by their embryology, and further by the known facts of palaeontology. In the case of these vascular plants we have the same anatomical gradation between fern, pine, dicotyledon and monocotyledon, and we trace it also in their development. The vegetative cells of the pine, or the antipodal cells of the flowering plant, are more easily regarded as fading heirlooms from a cryptogamous ancestor than as necessities. We should expect, therefore, to find in the geological record, fossils of vascular cryptogams before gymnosperms, and gymnosperms before dicotyledons; and, as a matter of fact, we do. In the coal measures, moreover, the divisions of gymnosperms and vascular cryptogams run almost indistinguishably together. There is also a curious parallelism in the nature of the developmental changes. The amphioxus was a marine organism developing in the water; the frog also spent the early part of its life in the same element. In the fowl we had a developmental history modified by the fact that the whole cycle occurred on land. The large store of yolk and the protective egg-shell are related to the necessity that the fish stages of the fowl should be got through before birth. The same necessity in the case of the rabbit is met by the embryo in its earlier stages being practically parasitic on the mother, through the intermediation of the placenta. In the case of these plants we have been studying we have in the fern prothallium an essentially aquatic type of structure; there is no vascular tissue and no distinct epidermis. Such structures, as we have seen, are correlated with a sub-aerial life. (Compare § 23, and Fucus, § 1.) The motile antherozoid also requires abundant water to reach the oosphere. But in the Phanerogams the prothallium stage of the life circle is parasitic on the sporophyte. The female prothallium grows, develops oospheres, and they are fertilised and well on the

way to the next sporophyte generation before the seed is released. In the mangrove an extreme case is seen of this retention. The seeds do not become scattered, but germinate while still in the fruit, and while the fruit still hangs from the parent tree, sending their radicles down from among its branches.

Questions on the Flowering Plant, Pine, and Fern.

1. Describe the structure and development of the pollen in any Angiosperm ; its mode of liberation from the anther, and transference to the stigma, and the subsequent internal changes which take place in it.
2. (a) Describe the structure of a Seed.
(b) How is an albuminous seed distinguished from an ex-albuminous seed ?
(c) Mention some of the forms in which nutrient material is stored in seeds.
3. What is the botanical definition of a Fruit ? Distinguish between *true* and *spurious* fruits.
4. Give an account of the morphology of the following fruits :—Apple, Strawberry, Orange, Fig.
5. Describe the process of reproduction in a Flowering Plant, and the minute anatomy of the structures involved.
6. Describe the structure of the Stamen of a Phanerogam. What bodies are produced by it, and what happens to them after they are shed ?
7. Describe briefly the mode of development and nutrition of the Embryo of a Dicotyledon, from the stage of the fertilised ovum to the period when self-support begins.
8. Describe any provisions for promoting scattering of the seed with which you are acquainted. Explain how each operates.
9. Describe the structure of a Ripe Seed. In what respect does it agree with, and in what differ from, the spore of a fern ?
10. Describe the structure of the mature ovule of a Gymnosperm, and point out the differences between it and the mature ovule of an Angiosperm.
11. Write the life cycle of *Selaginella*.
12. Describe the structure of the stamen and of a pollen grain of a Flowering Plant. What structures in a Fern correspond to these ?
13. Describe the process of impregnation in the ovule in *Phanerogamia* up to the formation of the embryo.

14. What are the resemblances and what the differences between the floral organs of an Angiosperm and those of a Pine (*Pinus*)?

15. Describe the structure of Pollen Grains, the development of the Pollen Tube, and the mode in which the fertilisation of the Oosphere is effected.

16. Give an account of the process of fertilisation in a Flowering Plant, and compare it with the process of fertilisation in *Fucus*.

17. Describe in detail the structure of the stem in *Pinus* after three years' growth in thickness. Explain how this growth in thickness takes place.

18. Describe the branching of the stem, and the characters and succession of the leaves in *Pinus*.

19. What is meant by an "alternation in generations" in the life history of a Plant? Illustrate your answer by reference to the life history of a Fern.

20. Give a general account of the structure of the rhizome of a Fern (*Pteris*) as seen in transverse section, and a detailed account of the structure of one of the larger fibro-vascular bundles.

21. Describe the general structure of the frond of a Fern, and state in what respects it differs from the leaf of a Flowering Plant.

22. Give an account of the structure and function of the Prothallium of a Fern.

23. Give a general sketch of the life history of a Fern, from the germination of the spore to the formation of the fertile frond.

24. Describe and compare the process of fertilisation in a Fern and in a Phanerogam.

25. Describe the sexual reproductive organs of a Fern and of a Flowering Plant, and state how fertilisation is effected in the two cases.

26. Explain clearly the biological meaning of—

- (a) Brightly coloured,
- (b) irregular,
- (c) regular, and
- (d) inconspicuous flowers.

TYPES OF ALGAE.

Fucus.

§ 1. The various flowering plants and the pine and the fern—in fact, all the vascular plants—are forms which, however much they may appear to differ at first, reveal upon analysis a remarkable family resemblance. They all present an alternation of generations, obvious or marked, and their stems and leaves are primarily adapted, by the possession of a distinct epidermis, to the needs of *a life out of water*. To this alone, too, is the presence of vascular tissue—transpiring tissue, that is—in their stems and the specialisation of the leaves ascribable. Some of them have, it is true, reverted to the water again, like the water lily, and then we observe a tendency to soften the epidermis and reduce the vascular bundles. The gradual reduction of the oosphere generation in these plants is also doubtless connected with the same tendency. The antherozoids of a fern can reach the ova only through the medium of water, and the prothallium must necessarily develop in a wet situation. But the process of pollination is relatively independent of moisture, and may occur in the driest position in which a plant can live. It is a process especially adapted to a life in air. In the life history of fern, pine, and sunflower we have in all probability the record of three stages in the conquest of the dry land, of its hillsides, and once arid tablelands by the vegetable kingdom.

§ 2. *Fucus*, the bladder-wrack, is a seaweed, and only very remotely related to these forms we have been studying. It has no alternation of generations, complete or reduced. Its vegetative body is without vascular tissue, and presents no differentiation into leaf and stem. Such a plant body is called a *thallus*, whence *Thallophyta*, the name of the great

subdivision under which *Fucus* falls. The thallus (Fig. 2, Sh. XIV.), of *Fucus* is attached by certain root-like processes. It is flattened, and branches dichotomously. Examined under the microscope (Fig. 3), it is seen to consist of an inner tissue of looser texture, the *medulla*, and of an outer, firmer, denser, and coloured *cortex*. The medulla consists of an interwoven network of filaments, each made up of a single row of cells (*trabecula*), embedded in a jelly-like tissue, formed by the degeneration into mucilage of the outer layers of the trabecular cell walls. The cortex consists of similar cells tightly packed to form a kind of parenchyma, and containing the chlorophyll corpuscles and brown colouring matter. The outer layers of the cortex are more closely packed to prevent undue desiccation of the plant at low tide. This outer layer is sometimes called epidermis; but as it has no special *dermatogen* at the growing point, and is otherwise indistinguishable from the cortex below, *pseudo-epidermis* (or *limiting layer*) is a better term. *Fucus*, when fresh, is a deep olive green or greenish brown. Put in fresh water or alcohol it almost immediately becomes the bright-green colour of ordinary chlorophyll. The brown tinge is due to the presence of a brown colouring matter (*phycophaein*), soluble in pure water and alcohol, which marks the green colour. Since chlorophyll is also soluble in alcohol, though not so quickly as phycophaein, the green colour will also go into solution, leaving the thallus at last a yellowish-brown colour.

§ 3. There are several species of *Fucus* occurring on the shores of this country. *Fucus platycarpus* has a flattened thallus, *Fucus serratus* is distinguished by its serrated edge, and *Fucus vesiculosus* secretes vesicles of gas. The bladder-weed of the Saragossa Sea is also a vesiculated *Fucus*.

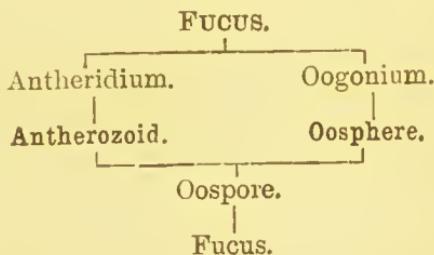
§ 4. The reproductive organs are contained in flask-shaped depressions of the cortex, the *conceptacles*, visible to the naked eye as small dots on the thallus. Each conceptacle has a rounded aperture, the *ostiole*, and contains a great number of *paraphyses* (=sterile hairs), which project through the ostiole. They also contain hairs bearing the sexual

organs. Most species of *Fucus* are monoecious, that is, with male and female conceptacles on one thallus; but some are dioecious, and some occur with hermaphrodite conceptacles.

§ 5. Figs. VIII., IX., and X., Sh. XIV., show successive stages in the career of a female organ or oogonium. Fig. VII. is a female conceptacle with its paraphyses (*pa.*) and ostiole. *oog.* are the oogonia, really inflated cells with double walls (*ex.* and *in.*) at the end of short unbranched hairs; the contents of these divide into eight oospores. The oogonia are liberated at low tide by the rupture of the outer coatings (*ex.*, Fig. IX.). The inner coating also ruptures at the ostiole, and the oospheres, which are now naked protoplasmic masses, await the coming of the spermatozoids (= antherozoids), which occurs as the tide rises over the plant.

§ 6. Fig. IV. is a male conceptacle. The antheridia (Fig. 5) occur on branched hairs therein, and give rise to many spermatozoids (or antherozoids) by internal division. The antherozoids crowd round the oosphere, causing it to rotate rapidly by their motion, and one enters and fertilises it.

§ 7. The fertilised oosphere (*oospore*) forms a cell wall, and proceeds in all probability to develop into the thallus again, so that the life cycle of *Fucus* may be represented thus:—



Spirogyra.

§ 8. In *Spirogyra* we have a still simpler Alga than in *Fucus*. In *Fucus* the cells build up a solid mass, but in *Spirogyra* we have mere strings of cells, called **filaments**. *Spirogyra* is common in the green scum of ditches. A cell examined under the microscope is seen to be typically parenchymatous (Fig. I., Sh. XVI.), and contains vacuolated protoplasm with a central nucleus. The chlorophyll is here not in simple corpuscles, as it is in all the types we have hitherto considered, but in a *spiral* band (chromatophore), which gives the genus its name. In this grains of starch may be detected after exposure to the sunlight. The starch grains are contained in small bodies in the chromatophore, called *pyrenoids*.

§ 9. All the cells of *Spirogyra* are alike. There is no differentiation at all; no cells in particular are set aside for fixation, for reproduction, for the transit of water, or for support. One cell could live quite as well by itself as in the filament. Going from *Spirogyra* upward in the plant series, we find a gradation of histological modification. In *Spirogyra* all cells are alike; in *Fucus* the paraphyses and sexual hairs are differentiated, and the root cells have no chlorophyll, but all are still parenchymatous; while in the higher series we find a large variety of cell changes, into sieve tubes, vessels, xylem fibres, phloem fibres, cambium and cambiform cells, idioblasts, pollen grains, and so forth, to make up the complete plant body.

§ 10. *Spirogyra* grows by cell division. The nucleus divides, the halves separate, and a cell wall is completed between them. This occurs particularly at night.

§ 11. The number of filaments may increase by their artificial or naturally accidental division. This is of course

the vegetative method. Besides this there is a process called **conjugation**, which may be compared to the sexual process in the forms above *Spirogyra*. Successive stages in this process are shown in Figs. II. and III., Sh. XVI. At 1 two filaments about to conjugate send out projections of their cell walls which meet, (2) to form a canal between the two cells. The cell contents contract away from the cell wall, expelling the sap from the vacuole. One cell then moves towards the other (3), and fuses with it 4 and 5. The resulting spore (*zygospore*) proceeds at once to invest itself with a cell wall, and may then rest for some time before germinating (Fig. IV.).

§ 12. This *conjugation* differs from sexual *fertilisation* in the likeness of the two elements that unite. They only differ in one being slightly more active than the other, and moving out of its cell to meet its partner. Since in the higher sexual process the antherozoid is the most active, this cell that moves in *Spirogyra* is sometimes spoken of as the male. In *Mesocarpus*, a relation of *Spirogyra*, the conjugating cells are exactly equivalent, and meet midway in the communicating tube. In *Fucus* the male and female elements are both free naked cells, but the male is *smaller and more active* than the female. In *Cutleria*, a brown seaweed allied to *Fucus*, the female gametes are motile and similar to the male, but larger. Both elements in *Fucus* are derived from the *division* of a parent cell, the oogonium cell dividing into eight and the antheridium into sixty-four. In the fern the contrast of the active numerous antherozoids and the *single* ovum is very much greater. As the separation of the sexual elements becomes wider, we see more and more clearly, in the greater amount of cell division in the male reproductive organs, as well as in many other ways, that *the male is essentially katastatic and energetic, the female anabolic, nutritive, and passive*. Turning to the animal types, the same difference is even more evident. Compare, for instance, the ovum of the fowl, with its enormous accumulations of yolk, with the spermatozoon of the same type.

§ 13. Although it is out of our province to offer any

explanation or to amplify the subject here, we may perhaps call the attention of the student to the universality of a sexual process among multicellular organisms, whether plants or animals. Every higher plant * and higher animal is at first a single cell comparable to the amoeba, but passive, with which another smaller and more active cell coalesces. This agreement must mark a common necessity, or a common ancestry, or both, or it is inexplicable.

* In some cases it is possible that fertilisation does not occur, *e.g.*, in Traub's Chalozophyta, and that the ovum develops by itself. In some cultivated varieties of fern it would seem that the sporophore generation arises as a shoot from the prothallium.

Vaucheria.

§ 14. *Vaucheria* is found as a greenish slime upon flower pots in greenhouses, and in ditch or brackish water. The plant body (Fig. I., Pl. XIV.), examined microscopically, is seen to consist of long filamentous threads *without any division* by cell walls into cells. Colourless root filaments serve for attachment. An extensive vacuole runs through the plant, and the protoplasm contains *numerous nuclei*. There is abundant chlorophyll in corpuscles of the usual character, but it is remarkable that no starch has been described in this type. Instead, *oil* (hydro-carbon) occurs in and about the chlorophyll grains.

§ 15. Some species of *Vaucheria* (*e.g.*, *Vaucheria tuberosa*) have a typical vegetative reproduction ; branches swell and become cut off by a cell wall, drop off, and become separate individuals.

§ 16. In *Vaucheria sessilis*, however, the detached branch has become specialised as a **spore** (=gonidium). Instead of falling off with its cell wall, this cell wall ruptures and liberates the contained protoplasm. The **zoospore** (=swarm cell or zoogonidium), as it is now called, has (Fig. I. 4) a number of nuclei towards its surface, and *cilia*, by which it moves in animal fashion through the water. After a brief interval, however, it retracts the cilia, becomes motionless, forms a cell wall, and proceeds to develop into the normal thallus.

§ 17. *Vaucheria* has a distinct sexual process. In Fig. A. the sexual organs of *Vaucheria sessilis* are shown. The male organ, or *antheridium*, is an upgrowth of the thallus cut off by a cell wall, and in which antherozoids appear. The oogonium, of which two usually accompany each antheridium, are also separate cells, with a beak-like aperture,

in which is a drop of mucilage, which may possibly serve to attract the antherozoids and secure the coalescence of one with the oosphere. The oosphere, when fertilised, forms at once a proper cell wall of its own, and remains passive until it germinates.

§ 18. Although *Vaucheria* has two methods of reproduction, there is no true alternation of generations. The same filament may bear zoogonidia and sexual organs in succession, and the plant developed from a zoospore is altogether indistinguishable from one developed from an oospore.

§ 19. It may not be out of place to say a word or two here upon the systematic position of *Vaucheria*, and therewith upon the cell theory in morphology. We have in "Biology," Part I., found it convenient to consider the rabbit as an aggregate of distinct cells, and we have spoken of the cells in a plant structure in very similar terms. A figure is thus likely to be created in the mind of the biological student of a multicellular organism as built of cells much as a wall is built of bricks—a false impression altogether; for in most cases the demarcation between cell and cell is more apparent than real. In bone, for instance, the protoplasm of the osteoblasts communicates through the canaliculi, and in parenchyma the protoplasm is probably continuous through the cell walls ("continuity of protoplasm"). There is no sharp boundary on the communicating threads where we can say, "At this point this cell ends and that begins." Hence, though the student will be prone to regard *Vaucheria* as a unicellular plant with many nuclei, he might just as reasonably regard it as a multicellular plant without dividing cell walls.

§ 20. In its sexual process, and in simple chlorophyll corpuscles taking the place of chromatophores, *Vaucheria* seems more closely akin to the higher forms than does *Spirogyra*. The filament of the latter is indeed a mere string of truly unicellular plants.

§ 21. Under certain unfavourable (*e.g.*, drying, etc.)

conditions *Vaucheria* may divide up by cell walls into a series of cells. This is called the **Gongrosira** condition. These may be separated from one another, and on the recurrence of more favourable circumstances these may either germinate at once into normal *Vaucheria* filaments again, or their contents may break up into naked amoeba-like bodies, which migrate, settle down, form cell walls, and develop.

SHEET XIV

1. *Vauchia sessilis*, thallus.

ASEXUAL CYCLE.—1. Separation of zoosporangium by a vacuole, and 2, by a cell wall. 3. Escape of naked zoospore. 4. which moves actively like an animal, then settles down, forms a cell wall, *c. w.* 5. and proceeds to grow as a plant into the thallus, 6. again.

SEXUAL CYCLE.—A. Oogonium and antheridium. B. The latter dehisced to liberate the antherozoids, *az.* C. Ripe oogonium with a drop of protoplasmic substance, *m.* in its beak, and the oosphere shrunk away from the cell wall. D. Ripe archegonium with the fertilized oosphere, the oospore having its own proper cell wall *c. w.* From this develops the thallus, E.

2. *Puccinia vesiculosus*. Thallus, with fertile branch, *con.*

3. Section of thallus.

4. Male conceptacle with antheridia and sterile hairs, the paraphyses; *os.*, the ostiole.

5. Fertile hair from male conceptacle with antheridia.

6. Antherozoid.

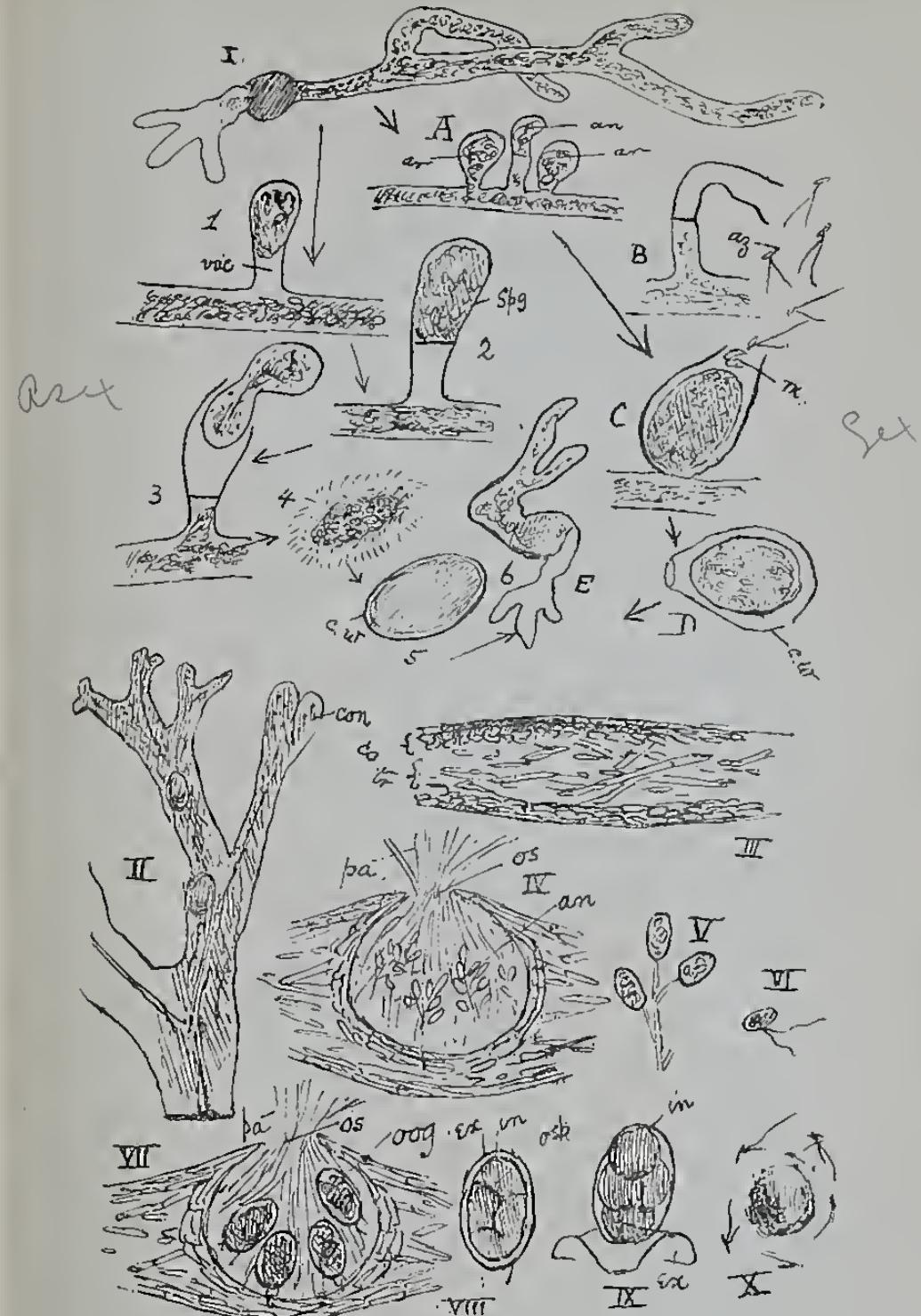
7. Female conceptacle with oogonia.

8. Fertile hair from female conceptacle.

9. Rupture of the extine liberating intine, which drifts to the ostiole, and there ruptures to liberate oospheres.

10. Fertilization of an oosphere.

To face page 86.





Questions on Algae.

1. Compare briefly the modes of increase in number of individuals in—
 - (a) *Fucus*;
 - (b) *Vaucheria*;
 - (c) *Spirogyra*;
 - (d) a Fern;
 - (e) *Pinus*.
2. Give a brief sketch, with explanatory diagrams, of the reproductive organs of *Fucus*.
3. (i) What is a Spermatozoid (antherozoid)?
(ii) In what plants do Spermatozoids appear?
(iii) How are they developed and set free?
(iv) What is their function? and how is it performed?
4. Give an account of the structure and life history of *Vaucheria*.
5. Write an account of the life history of *Fucus*. Compare its mode of fertilisation with that found in *Spirogyra*.
6. Compare and contrast *Penicillium* and *Spirogyra* as regards their nutrition and reproduction.
7. Describe the vegetative organs of *Fucus*.
8. Compare "Conjugation" with Fertilisation.

PENICILLIUM, YEAST, AND BACTERIA.

Penicillium.

§ 1. All the vegetable forms we have hitherto considered have exhibited chlorophyll. Some flowering plants, however, have become parasites or saprophytes,* and have lost their green colour with the habit of independent assimilation, as is the case with the bird's-nest orchid. This absence of chlorophyll is rare among the higher plants, but among the Thallophyta an enormous number of cases occur. For this reason the Thallophyta have been divided into two chief series, the green Algae and the Fungi without chlorophyll. Some few among the Fungi, however, very closely resemble Algae in form, and may indeed be regarded as Algae that have lost their chlorophyll through their parasitic or saprophytic tendency.

§ 2. There are certain physiological consequences of this absence of chlorophyll. The Fungi apparently do not need iron, which is necessary to the formation of chlorophyll. Oil commonly takes the place of starch in their economy, and they are of course unable to use carbon dioxide as food. They need organic compounds. Apparently, however, they do not resemble animals in finding proteids indispensable. They can manage with much less complex organic compounds than these—anmonium tartrate, for instance. Fungus cellulose stains blue with iodine, without the previous action of sulphuric acid.

§ 3. *Penicillium* is the common blue mould. It is a mesh-work of strings of cells or hyphae. Its network is figured

* A parasite preys on living organisms, a saprophyte on their excreta or decaying remains. The term *holophytic* indicates a capacity, such as most plants possess, of living on entirely inorganic food.

upon Sh. XV. There is a general tangle or **mycelium**, and root-like *submerged* and vertically ascending aerial hyphae. The blue colour is due to the colour of the **gonidia**, which are formed abundantly upon erect or *aerial hyphae*, rising from the mycelial net. This reproduction by gonidia (Fig. II.) is practically the only reproductive process used by this plant. It is obviously scarcely at all removed from ordinary vegetative reproduction (*cp. §§ 15, 16*).

§ 4. Under exceptional circumstances, however, Penicillium will go through an altogether different life cycle. This is illustrated in Fig. III., Sh. XV. Two branches arise from the mycelium side by side, and coil closely round one another. *It is supposed* that one, the *ascogonium* (= *archecarp*), is female, and the other, the *pollinidium* (*p.*) is male, and that the contents of the latter pass into and fertilise the former.* A number of other hyphae arise round these two from the mycelium, and enclose them in a network, and finally in a solid mass, or *fructification*. The ascogonium grows in length (*C*), branches, and its branches subsequently divide into series of inflated cells, the *asci* (*as.*), in which are developed by endogenous cell division *as.s.*, the ascospores (*D*). Each ascospore is a flattened body, which under suitable conditions will rupture an outer coat (*E*) and reproduce the mycelium. The plant may remain quiescent at the fructification stage for a considerable time.

§ 5. Hence Penicillium has two alternative life cycles,—a rare one, involving an alternation of generations, an alternation between sexual process and ascospores, which is probably inherited from ancestors to whom it was of great value; and a common asexual one, which has largely superseded it.

* The doubt seems to be growing. Possibly fertilisation never occurs among Fungi.

Yeast (= Torula = Saccharomyces).:

§ 6. This plant is simply an aggregate of egg-shape cells containing vacuolated granular protoplasm with a small nucleus only to be demonstrated by special staining. It is the fungus of fermentation, and its common habitat is in saccharine solutions, in which nitrogen and sulphur are also present in small amounts. Normally it increases simply by **vegetative reproduction**; the cells sprout off buds, which may bud again and become detached (Fig. 7, Sh. XV.). The buds usually bud again before becoming free, forming “colonial” groups.

§ 7. Alcoholic fermentation is a chemical change set up in the solution in which the yeast lives, through its vital activity. It is a process essentially similar to katalysis in inorganic chemistry. In the presence of small quantities of yeast relatively enormous amounts of sugar will be converted into alcohol and carbon dioxide. The process may be roughly indicated by the equation—



But it must be clearly understood that, as a matter of fact, small quantities of glycerine, succinic acid, and other compounds are also formed.

§ 8. Besides the vegetative reproduction we have noted, yeast, under exceptional conditions, can be induced to form spores. This may be done by cultivating it upon some inhospitable surface—plaster of Paris, for instance—or the cut surface of a potato or turnip. Ordinary cells then increase in size, and their contents divide endogenously into four small cells, which remain quiescent until more favourable conditions supervene, and which are capable of enduring considerable extremes of drying and change of temperature.

§ 9. This has a certain resemblance to the formation of ascospores in Penicillium. This, coupled with the fact that such a high form as *Mucor** may, when immersed in a highly nutritive solution, assume a form similar to yeast, has led to the supposition that yeast has undergone **degradation**, and is what is called a degraded organism. It is supposed that it once had a more complicated structure and reproductive process, but that under an unbroken continuance of favourable conditions the need for these disappeared, and they have been entirely superseded by the simpler sprouting habit. A similar tendency to simplification is perhaps indicated in Penicillium itself by the relative variety of the fructification cycle.

§ 10. This is the only instance in our present course where with any certainty we touch upon **degraded forms**; though perhaps in bacteria, in amphioxus, and in the mussel we may have instances of the same phenomenon. It is well, however, for the student to bear in mind that evolution is not to be regarded as always a certain unswerving progress from lower to higher, from simple to complex, from undifferentiated to differentiated. In the case of yeast the stress of circumstances has indeed probably been driving in just the opposite direction, and the yeast has fallen back from a higher level.

* *Mucor* is a hypha-forming fungus, somewhat similar in its vegetative organs and habits to Penicillium. Placed in sugar solution, its spores develop and bud repeatedly in a manner quite similar to ordinary yeast.

Bacteria (Schizomycetes).

§ 11. The Bacteria are a group of exceedingly minute organisms which are commonly regarded as coming within the confines of the vegetable kingdom. They resemble the true Fungi (*Penicillium* and *Yeast*, e.g.) in having no chlorophyll, and most plants in having cell walls. But it is not quite certain that the cell walls are composed of cellulose, and no nuclei have been demonstrated in the group.

§ 12. Bacteria reproduce by cell division (fission), and in many cases also by spores. The spores of bacteria are excessively minute, and are suspended in immense numbers in the air. In spite of their size they play an important part in human affairs. Most epidemic diseases, for instance, are due to the multiplication of the spores of specific bacteria, and the destructive accompaniments of their development in animals or in man. The phenomena of putrefaction, again, are due to the vital activity of bacteria.

§ 13. The changes effected by these organisms in their surroundings are out of all proportion to their size and nutritive activity. Like the alcoholic fermentation of yeast, the changes they initiate are initiated katalytically. Putrefaction is essentially a catabolic change of proteinaceous matters, with the disengagement of the characteristic odours of H_2S and NH_4S , through their influence. It may, therefore, be stopped by any means which prevents the access of bacteria, destroys them, or arrests their vital processes. In the last category comes extreme cold (e.g., in a refrigerator) or heat, which, although it does not destroy the extremely hardy spores, prevents their development while it continues. Another line of prevention is the use of antiseptic substances. Blocking the access of bacteria is the method employed in the case of tinned provisions. These, before they are sealed up, are boiled twice. The second boiling

SHEET XV.

1. *PENICILLIUM*. *a. hy.*, aerial, *s. hy.*, submerged, and *my.*, ordinary mycelial hyphae

2. The asexual cycle of the same. *s. g.*, sterigma, from the end of which (*s₁*) styloconidia are successively cut off (*st₂*) to develop directly (*st₃*) into mycelium again.

3. Sexual (?) process. *asg.*, ascogonium intertwining with pollinodium. *p.*, *c. h.*, sympathetic development of hyphae from mycelium (*my. h.*) destined to enclose the ripened ascogonium.

B., Later stage. The "fructification" tangle derived from *c. h.*.

C., Branch of an ascogonium (isolated) developing (D.) into asci containing, *as. s.*, ascospores. E., ascospores enlarged, and F., developing.

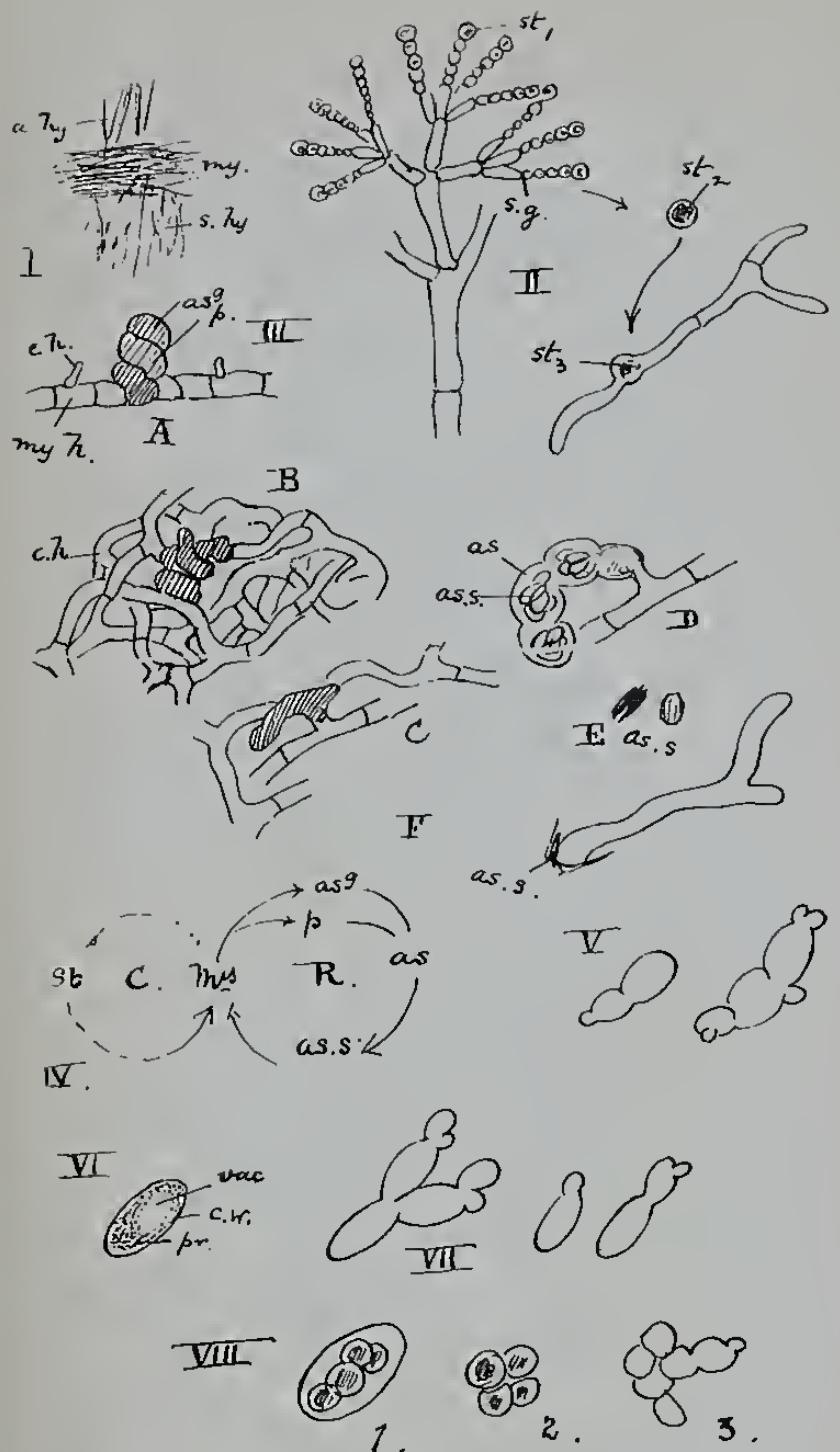
4. Life cycle diagram.

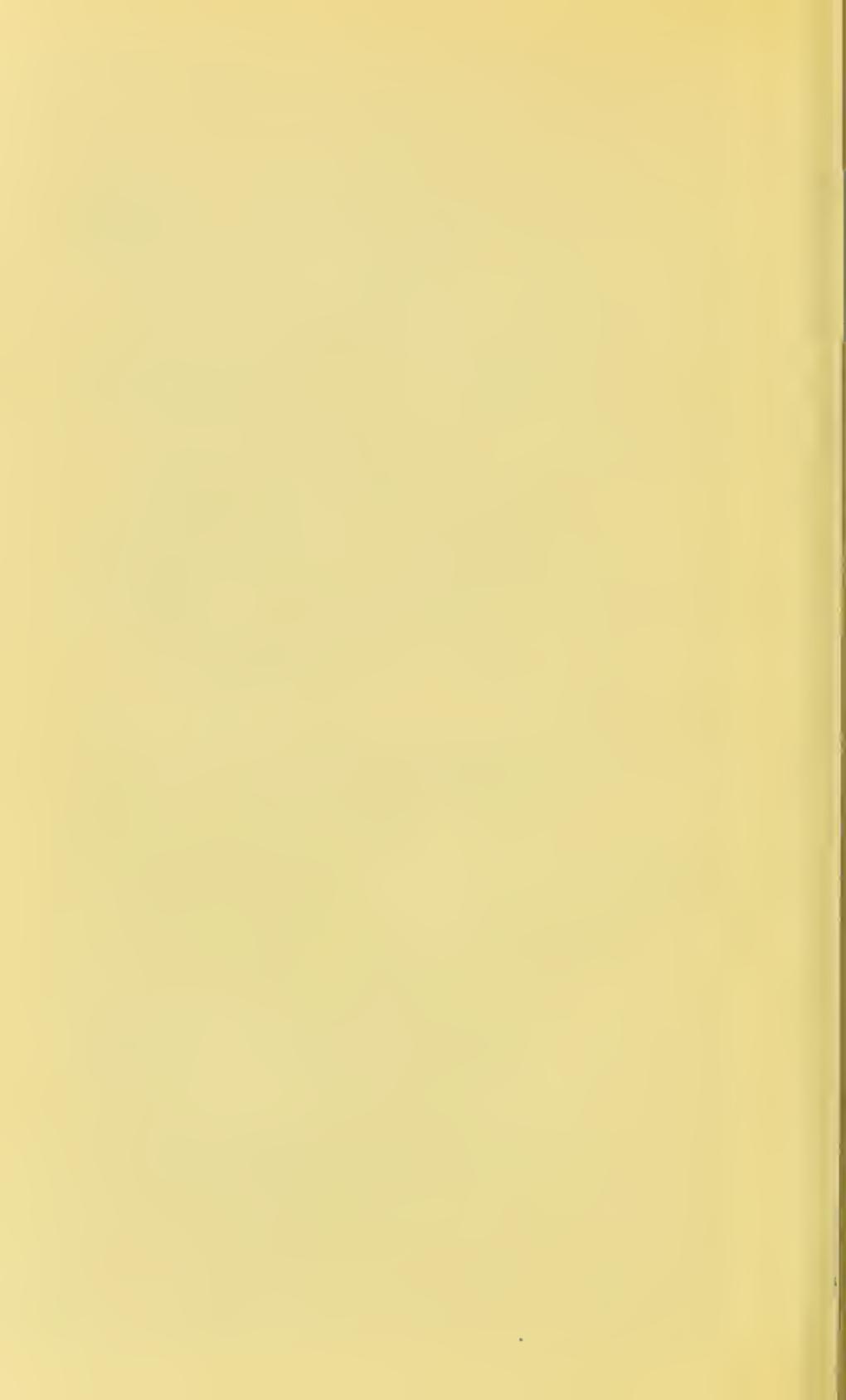
5. Mucor yeast. A degraded form of *Mucor* obtained by immersing it in a highly nutritious saccharine medium.

6. Yeast cell.

7. Yeast sprouting.

8. Formation of ascospores in yeast.





is necessitated by the hardiness of the spores. The first simply destroys the developed bacteria, but not the spores that may be present. These, as the substance cools, proceed to germinate, and so are destroyed by the second boiling.

§ 14. The forms of bacteria are very various, but some considerable doubt exists as to whether many of them are to be regarded as distinguishing different species, or simply as different stages in the life circles of the same organism. *Micrococci* are dot-like organisms; *bacilli*, short rods; *vibriones*, vibrilate rods; *spirilla*, flagellate, coiling forms, for instance. Most bacteria, where they appear, appear in enormous numbers. In many forms the cell walls readily swell up to a mucilaginous texture, and the swarms of bacteria then form a jelly or zooglea.

§ 15. On Sh. XVI. are figured stages in the life circle of *Bacillus anthracis*, the disease germ of the disease called *anthrax*. *B. a.* are forms such as occur in the blood of the affected animal, simply filaments of short rod-like cells. This may be called the *parasitic* stage of this species. If shed by the host in any way, spores are formed, as at *sp.*, in successive cells. These spores may remain for a considerable period unaltered, until they obtain a footing in a host again, *e.g.*, by being eaten with herbage by cattle. The disease then develops rapidly, and consists essentially of fermentative changes set up through the presence of the parasite. Most of the great epidemic diseases—cholera and the various fevers—are the consequences of bacterial by-products. Consumption and hydrophobia are also among their beneficent activities.

§ 16. The phagocytes, which occur so abundantly in the Peyer's patches, vermiciform appendix, tonsils, and in botryoidal and connective tissue generally in animals, will attack, ingest, and destroy bacteria that have invaded the organism. No doubt the activity of these remarkable cells is the reason of the general immunity from the ever-present contagion floating in the air; and any weakening of the

system that affects their activity paves the way for the attacks of epidemic diseases. The disease germs evidently fall under our definition of parasitic organisms. The greater part of what is valuable in our knowledge of the activity of these forms has been derived from experiments upon living animals. Many bacteria are entirely saprophytic, however (putrefaction forms, *e.g.*). Clearly resembling bacteria are the very minute algal organisms, the Cyanophyceae, but these contain chlorophyll, and are holophytic.

Students who feel sufficiently interested in the subject to extend their botanical reading beyond the mere pass requirements, will find *Sach's Physiology of Plants* a really inspiring book, although in some respects it is unfortunately out of date. A more modern book is *Vines*. For botanical mythology the best text-book is perhaps that by *Goebel*. Those who would extend their knowledge of flowering plants should get any good British Flora, and gather in and identify as many specimens as possible.

Questions on Fungi.

1. Is it possible to grow a mould and a flowering plant in aqueous solutions artificially prepared? State what should be the ingredients of such solutions, and explain in what important respect they must differ in the two cases.
2. Give a full account of the differences which exist between an Alga and a Fungus with regard to the mode of their nutrition.
3. (a) What is a Parasite? Give an example.
(b) How is a Parasite distinguished from a Saprophyte? Give an example of a Saprophyte.
4. Briefly describe and contrast the processes of nutrition in *Spirogyra* and *Saccharomyces* (Yeast Plant) respectively.
5. Give a general account of the phenomenon of Putrefaction. Describe the life history of the organisms by which it is caused, and the methods which are available for arresting their development.
6. Write the life history of *Penicillium*.
7. Write the life history of the Yeast Plant, and mention the points in which this plant resembles and differs from *Penicillium*.
8. Describe the structure, functions, and life history of the Yeast Plant (*Saccharomyces*).
9. Describe the female sexual organ in *Vaucheria*, *Fucus*, and *Penicillium*.
10. Describe and contrast the development of the asexual spores of *Penicillium* and *Vaucheria*.
11. Draw a series of diagrams illustrative of the development and structure of *Penicillium*. Explain them by brief notes.
12. Describe the structure and position of the sexual reproductive organs in *Penicillium* and a Flowering Plant. Describe the reproductive process in each case.

PROTOZOA.

Plant and Animal.

§ 1. In comparing a flowering plant with a vertebrate we might draw up a very considerable list of differences. Among the chief of these there would be :—

- (i) The plant's eells have *cellulose* cell walls. The plant absorbs ; the animal ingests.
- (ii) The plant *can* live entirely on inorganic food by virtue of its chlorophyll. In its entire scheme anabolys exceeds kataboly. The animal needs proteids.
- (iii) The plant is fixed ; the animal motile, and therefore often with organs of touch, sight, hearing, and so forth, working together through a nervous apparatus.

But as we descend in the scale of the plants these distinctions begin to fade. The antherozoid of the fern, the conjugating oosphere of fucus, are free cells without cell walls. This upsets our ideas about the cellulose cell walls, and the plant being necessarily fixed and the animal free. Moreover, the mussel, we shall see, has become as passive as a plant almost, and the adult oyster and ascidian never move. Amoeba and Vorticella, again, have no nervous system. The fungi weaken the distinction based on the food by their need of organic substances. It is not absolutely certain, though it seems highly probable, that all animals do require proteids in their food, while the fungi are content with simpler organic compounds. Two animals we study, *Hydra* and *Vorticella*, we may also observe here, often possess *chlorophyll*. We have therefore to modify the above statements very considerably, to insert "typically," "generally," and the like qualifications, if we wish to retain them. A plant, we may say, for instance, is an organism in the life history of which the dominant phase, at least, is a cell or cells with cellulose cell walls through which food

must needs diffuse in solution ; while in the animal cellulose cell walls are absent, and solid food is taken into the body. When we reach the unicellular organisms, we find forms that it is quite possible to call either animal or vegetable. The Mycetozoa, for instance, are described by Lankester, in the "British Encyclopædia" article, *Protozoa*, and by De Bary in his, *Fungi*. This impossibility of drawing a line between the vegetable and animal kingdoms is evidently entirely in harmony with the evolutionary view. Somewhere in the region of the unicellular organisms the lines of the ancestry of higher plant and metazoon must converge. However, our choice of types includes none in really debatable territory. Yeast and bacteria have still the fundamental characters of plants—cellulose cell wall and so forth ; and in Amoeba we find beyond all question an animal form, motile, naked, and ingesting.

Amoeba.

§ 2. In "Biology," Part I., p. 19, this form is briefly described; and to that chapter on Cells and Tissue the reader should refer, if he encounters any difficulty in what follows here. We may add here to the description there given, that amoebae are sometimes found with two or more nuclei. This fact is of interest in connection with what we have said concerning *Vaucheria* (§ 19). *Amoeba*, under stress of unfavourable circumstances, will become motionless and form around itself a protective wall. This is called **encystment**, and the protective case is a *hypnocyst*. It is sometimes stated that *Amoeba*, after such encystment, will break up into a number of small spores or "*amoebulae*," but too much credit must not attach to this statement. The simple fission described in Part I., if not the only reproductive process, is certainly the only prevalent one.

§ 3. In the division of the nucleus of Protozoa, the phenomena of *karyokinesis*, which we have described as the common feature of most cell division among the multi-cellular organisms, is not observed. Species of amoebae are among the commonest ditch water and pond organisms. Parasitic amoebae are also stated to occur (Neumann), but more probably these are Sporozoa. *Amoeba* is simply a minute dot to the naked eye. For figures, see Sh. XVI., 8.

Vorticella.

§ 4. In this type, as in Amoeba, we have a unicellular animal—a protozoon; but the structure of this single cell is far more complex than any we have hitherto considered. So far as the types we study are concerned, Vorticella stands by itself, an animal specialised along a line of its own. Amoeba is simply homogeneous-looking protoplasm, with a nucleus, containing a nucleolus, and a contractile vacuole; it is without definite shape, and it performs the functions of ingestion, defaecation, and digestion indifferently at any region of its body. Vorticella has a nucleus of a peculiar character with no contained nucleolus; has a definite mouth region, an anus region, a marked and characteristic form, and its protoplasm is differentiated externally to form a cuticle, and internal to that to form muscle striations. It is, in fact, a complicated organism. But while the complication of a metazoon may be regarded as a specialisation of imperfectly separated cells, one to become a muscle fibre, one a cartilage corpuscle, and so on, the complication of Vorticella arises by the specialisation of what are certainly different regions of one and the same cell.

§ 5. A typical zooid (= single animal) of Vorticella is seen in Fig. 7. Its general form is that of a wine glass with a very long flexible *stem*, by which it is attached to weeds and twigs in the water. The stem is hollow, and a contractile filament runs through it, and by its contraction throws it into a spiral form. The protoplasm of the body is granular, and externally it is permanently differentiated to form a *cortex*, outside which is a secreted cuticle. At the base of the wine glass, faint protoplasmic striae, the *myophyan striations*, comparable to the longitudinal striations of muscle fibre, are seen in the cortex. There is a *contractile vacuole*. A spiral of cilia, exactly like the cilia of ciliated epithelium, runs round the rim of the wine glass, and is

called the **peristome**. It terminates internally in a funnel-shaped *pharynx*, and the ciliary current is continually driving small particles of food into this. All egested matter is got rid of at one spot near the pharynx. This spot, however, is not visible as an opening, except when rejected matter is escaping, and it is called, therefore, not an *anus*, but a *potential anus*. There is no alimentary canal between these two points. At the bottom of the pharynx the food particles pass into the general protoplasm of the body, along with a drop of water, as *food vacuoles*, and circulate therein while undergoing digestion.

§ 6. The **nucleus** is entirely exceptional among the cell nuclei we have hitherto considered. It is band-shaped, and the band is often in the form of a **U**, **J**, or **C**. It is often spoken of as the *endoplast*. A similar body of denser protoplasm, the *endoplastule*, which has been regarded as a nucleolus, lies beside and outside it.

§ 7. Vorticella, like Amoeba, may undergo **encystment**. An encysted vorticella is represented in Figs. 8, 6, Sh. XVI. The stalk is thrown into a close spiral, and the peristome is retracted. A similar but more temporary retraction of the peristome is seen when cell division occurs, or when the vorticella is alarmed.

§ 8. A process called **conjugation** occurs in Vorticella, but the word here hardly has the same reproductive import that it has in Spirogyra (§ 11). Two of the ordinary vorticellae become approximated and fuse. What occurs between the two in the case of Vorticella is unknown; but in the conjugation of related forms the endoplasts would appear to coalesce and break up, and the endoplastules to unite and constitute new endoplasts; while the vestiges of the old endoplasts become the endoplastules of the reconstituted zooids. After some time—whatever may happen—the vorticellae separate again. The physiological advantage of this to the animal is quite unknown.

§ 9. Reproduction is by cell division. This may be either

SHEET XVI

1. SPIROGYRA. *ch.*, chromatophore

2. Stages in the so-called sexual process. 1, 2, 3, 4, 5 (zygospore).

3. Hyphae containing zygospores.

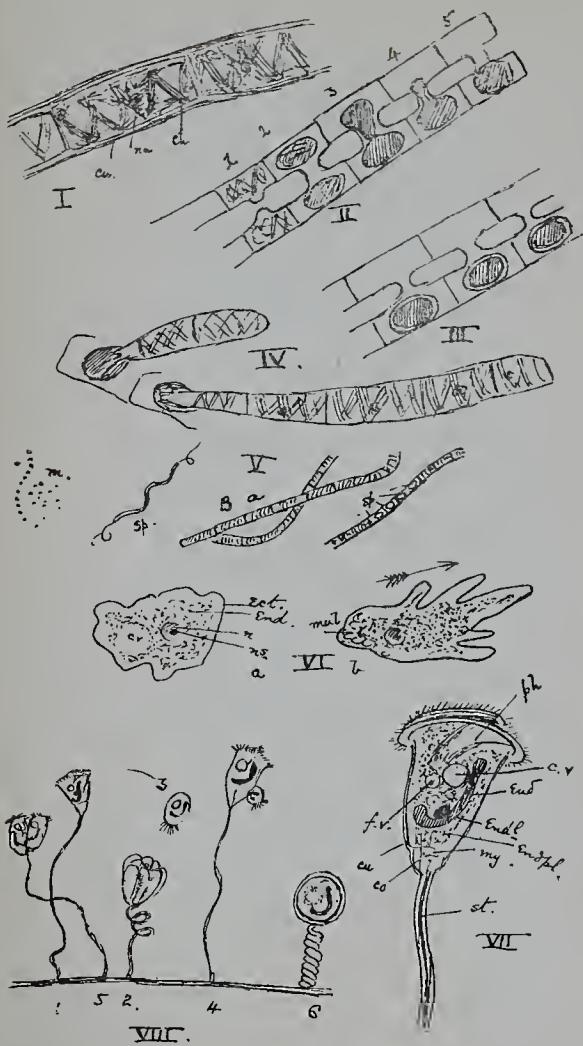
4. Germination of the same.

5. Forms of BACTERIA Micrococci (*m.*) Spirillum (*sp.*). B. A., Bacillus anthrax, with a hypha forming the characteristic spores (*sp.*).

6. AMOEBA. *end.*, endo-, and *ext.*, ecto-plasm. *b.*, an Amoeba in motion, showing pseudopodia. The part of the animal undergoing retraction has a mulberry-like appearance (*mul.*)

7. Vorticella zoid. *endpl.*, endoplasm. *end.*, endoplast *endl.*, endoplastule. *co.*, cortex, with *m.*, myonuclear striations *cu.*, cuticle *ph.*, pharynx. *st.*, contractile fibre in stalk

8. Phases of Vorticella. *N.B.*, These are not successive. 1, Extended. 2, Retracted and undergoing fission into 8 microgonidia. 3, microgonidium. 4, conjugating with a normal zooid 5, Binary fission. 6, Encystment.





binary fission or multiple division. In binary fission (Fig. 5), the vorticella splits longitudinally—after, of course, nuclear division—and one of the two halves frequently becomes detached from the stalk, develops an aboral* circlet of cilia, and swims away, in all probability to coalesce later with some other vorticella.

§ 10. In multiple division (Figs. 2 and 3) the zooid is divided by eight radial vertical planes into eight “*microgonidia*,” miniature editions of the free vorticella with aboral cilia. These all swim away ultimately to meet with and coalesce with the typical stalked forms.

§ 11. The relation—if any constant relation exist—between these unions of cells and subsequent division has not been by any means clearly formulated yet. Apparently the union of a free motile *microgonidium*, with a large, sessile, and (comparatively) inactive vorticella, is frequently followed by increased activity in the latter and its division. This has been compared to the sexual process of the metazoa, in which a small active free cell unites with and stimulates a large inactive cell to repeated division. But too much value must not be given to such comparisons as this, showing that a sexual process or something analogous to it occurs in the unicellular organisms. (Compare Part I., p. 20, § 51.)

§ 12. Vorticella is found abundantly on floating vegetation in ponds. The crowds of zooids appear simply as a grey film to the unaided eye.

§ 13. It would appear that Vorticella occasionally occurs with chlorophyll (*Vorticella viridis*). Commonly, however, it is colourless. The chlorophyll is stated by Sallitt to be diffused evenly through the protoplasm—not contained in chlorophyll corpuscles, as it is in *Hydra* and most plants. It is extremely doubtful if *Vorticella viridis* is holophytic. Allied to Vorticella are numerous “colonial” forms of Infusoria, the stalks of which branch and bear the individual zooids at the end of their branches.

* *I.e.*, at opposite end to mouth.

Questions on Protozoa.

1. Compare with one another as to elaboration of structure the unicellular animals Amoeba and Vorticella. Contrast their structure and mode of life with that of the Yeast Plant and of Spirogyra.
2. What are the differences between Plants and Animals? What are the reasons for not regarding the Spermatozoid of Vaucheria as an animal?
3. Describe the structure and life history of Vorticella. In what respects does Vorticella resemble Amoeba, and in what does it differ from it?
4. (a) Describe the general form of Vorticella ;
(b) the different external and internal organs which it possesses, and their supposed functions ;
(c) its mode of reproduction ;
(d) any other features of importance connected with its life history.
(e) What is the most important difference between Vorticella and Hydra ?
5. Describe the structure and life history of Amoeba, and compare its mode of nutrition and chemical activity with that of Spirogyra and of the Yeast Plant.
6. Compare the division of Amoeba with the segmentation of the ovum of Amphioxus.

In the general part of the article *Protozoa*, in the "British Encyclopædia" the reader will find an amplification of what is here given, and following this is a systematic review of the group.

HYDRA.*

§ 1. The Hydra is the simplest multicellular organism we have to study. Its body is simply a two-layered sac with one opening, the mouth (called also by some writers the *blastopore*), mounted on a conical elevation, the *hypostome*. This opening also functions as the anus. Around the mouth are a number of tentacles, radially arranged, by which food is seized. They are extremely flexible and hollow, the archenteric cavity being continued into them. The whole animal is capable of considerable extension and retraction as it reaches after its prey (see Fig. 1). In Part I., p. 103, we have already compared this type with the gastrula, and from the facts given there of the development of amphioxus it is evident that the central cavity of hydra, the *archenteron*, = the mesenteron and coelom of the higher types. On this account hydra is placed with the coral polyps, jelly fish, and other allies in a division Coelenterata, in distinction from the Coelomata, those metazoa that possess a coelom distinct from the alimentary cavity.

§ 2. The **body wall** of hydra consists of two cellular layers divided by a highly elastic structureless secretion, the *supporting* or *middle lamella* or *mesoglaea*. This is also called the mesoblast in some books—a most objectionable use of the word, since mesoblast is in all other cases a name for a mass of *cells*. The layer external to the *mesoglaea* is the *ectoderm* (= gastrula epiblast); the inner layer is the *endoderm* (= primitive hypoblast).

§ 3. The **ectoderm** consists of a number of large pyriform cells which are inwardly produced into vertical tails attached to the *mesoglaea*. These tails are contractile and

* This and onward is best read after finishing Part I.

longitudinally striated, and by their contraction they effect the great changes in form of which the hydra is capable. They present an interesting intermediate condition between the unspecialised cell and the quite differentiated fibre of the unstriated muscle of the higher types. At the foot the ectoderm cells are modified for the purpose of adhesion. Besides these muscle-tail cells there are abundant smaller *interstitial* cells, but these are absent from the foot. Some of these undergo development into the peculiar stinging thread cells (*nematocysts*) of this type. Such a cell is shown in Diagram XVII., 8. Within the body of the cell a long hollow filament is coiled. At the apex of the cell there is a small structure called the trigger (*endocil*). Before discharge the thread cell is rounded and its contents apparently under considerable tension. Upon irritation the thread is suddenly and very forcibly shot out, being turned inside out (*everted*) in the process. The thread while it is in the cell may be compared to a glove finger tucked in (*introverted*); its discharge resembles the pulling out (*eversion*) of the inturned glove finger. There are large solitary nematocysts, and also smaller ones, gathered in "batteries" on the tentacles. There are distinct nerve cells in hydra connected by processes. These are especially abundant round the hypostome.

§ 4. The **sexual organs** are derived from the ectoderm, and are of the simplest kind. Interstitial cells multiply and form a small wart-like swelling. If this swelling is to be a *testis*, cell division proceeds, and these cells give rise to *spermatozoa* of the usual type. The testes occur usually towards the mouth end of the body. If, on the other hand, it is to be an *ovary*, one cell becomes amoeboid, grows externally, consuming the others, and becomes the *ovum*. Testis and ovary may occur on the same hydra, and simultaneously. Hydra is thus distinctly *hermaphrodite*. The ovaries are usually nearer the foot than the testes, but not always.

§ 5. The **endoderm** consists of much larger cells than those of the ectoderm. They often bear single whip-like processes (*flagella*), which differ from *cilia* in their length

and the variety of their movement. Food is actively ingested by the endoderm cells. They often contain, and especially in the neighbourhood of the mesoglaea, chlorophyll grains exactly like those of the higher plants, and they further resemble the typical plant cell in having extensive *permanent vacuoles*.* They also function in diminishing the calibre of the body cavity. The endoderm in the hypostome is of a more columnar form, and probably secretes a digestive fluid.

§ 6. It has been suggested that the chlorophyll grains are not an integral part of the hydra at all, but unicellular algae which are parasitic upon the hydra, not preying upon it, however, but assisting it by forming organic compounds in return for its CO₂. Such mutual help unions certainly do occur—in the case of the lichens, for instance, where a fungus and alga co-operate—and the term **symbiosis** is used to indicate the connection, but it is extremely doubtful whether the green grains of hydra are to be regarded as symbiotic unicellular plants. They resemble in all respects typical chlorophyll grains, and it is hard to say, if they are to be regarded here as separate organisms, lodgers as it were, why they should not be so regarded when they occur in a leaf.

All specimens of hydra are not green; some are brown, and some almost colourless. The three forms have been distinguished as separate species, *Hydra viridis*, *Hydra fusca*, and *Hydra vulgaris*, but more probably they are varieties or even simply stages in the life history of the same species.

§ 7. Besides the sexual process of hydra, this form also multiplies by **budding**. A warty prominence grows out, develops arms, archenteron, peristome, and mouth, and becomes detached as a perfect hydra. The two halves of an artificially bisected hydra will also become perfect individuals. In very many Coelenterates the budded individuals do not become detached. They remain continuous

* The student should keep clearly before his mind the three classes of vacuoles: food vacuoles (*e.g.*, Amoeba), contractile vacuoles (*e.g.*, Amoeba), and permanent vacuoles, as here.

with the parent and bud again, giving rise to branching stocks of individuals, or *colonies* as they are called. This budding is of course *vegetative reproduction*. It does not occur conspicuously among the particular coelomate types that we have to consider, but it is by no means rare among the Coelomata. Among the Tunicata, for instance, which are chordate animals distantly related to amphioxus, it occurs, and in many worms. The "sea mats," again, are colonies of coelomate forms. Even among our types what is closely akin to vegetative reproduction, the replacement of parts of the body lost in any way, is shown by the worm, which can restore whole segments, and by the crayfish, which will grow lost limbs again. In the mammals this has dwindled to a mere healing power, and the larger mutilations are permanent.

§ 8. In the development of the ovum the gastrula stage is not, as the student might expect, attained by invagination. After a practically equal segmentation a solid mass of cells is formed. This differentiates into internal (endoderm) and external (ectoderm) layers; a cavity (the archenteron) appears among the internal cells, and the mouth (which may or may not be a true blastopore) is formed by dehiscence. While this development is proceeding an outer coat is formed by the most superficial portion of the ovum and cast off. At one stage the boundaries between the individual cells of the ovum become extremely indistinct. The individual cells seem to fuse together again. This incidental condition is spoken of as *histolysis*.

§ 9. Comparing hydra with a protozoon, the great point to notice is, of course, that it is a metazoon. *Instead of the whole body engaging in the reproductive process, certain of the interstitial cells alone are selected to carry life on to a new generation.* Most of the cells of the hydra (except they enter into buds) are destined to perish with the individual—they have a definite end when the individual dies; while every protozoon cell is also potentially a reproductive cell and quasi-immortal. The natural and inevitable

end of the metazoon individual is death. On the other hand, the death of a protozoon is an accident rather than an inherent destiny.

§ 10. Comparing hydra with a coelomate animal, the fundamental difference is, of course, its being *coelenterate*. Its cells have undergone specialisation to particular duties, but they are not nearly so much *differentiated* as the tissue cells of higher forms. The greatest modification is seen in the nematocyst. We find no tissues in hydra containing matrix and fibres, the only secretion external to cells is the mesoglaea. Compare with this the varied complexity of connective and nervous tissue, blood, striated muscle, and Haversian systems of bone, in the rabbit. Hydra has no differentiated nervous centres, and of course no sense organs; and all the sets of organs that follow upon the separation of the mesoblast in the development of the higher types, renal, circulatory, and skeletal, are wanting. One other point of contrast is particularly striking. In hydra the reproductive organs are epiblastic. In the other metazoa *that we study* this is not apparently the case. (See Rabbit, § 144.)

§ 11. Hydra is a common inhabitant of green ditches. It is visible to the naked eye, being, when contracted, about the size of a pin's head, or larger. Living specimens should be examined by the student.

Questions on Hydra.

1. Give an account of the anatomy of *Hydra*, and of the methods by which it can reproduce itself.
2. Give an account of the ultimate structure of the body wall of *Hydra*, and of the functions which its parts are supposed to discharge.
3. Describe, severally, the structure and the functions of the cells which build up a *Hydra*.
4. (a) Describe from without inwards the structures visible in a transverse section of a *Hydra*; (b) describe similarly a transverse section of an Earthworm taken about the fortieth segment.

In both cases describe the tissues present and the characters of the cells which form them. (c) State what is the most important structural difference between *Hydra* and the Earthworm as shown by these two sections.

5. In what essential respects does the structure of *Hydra* differ from that of *Vorticella*? Describe the methods of reproduction in each of these animals.
6. Give an account of the structure of *Hydra*, and of *Vorticella*. What is the fundamental difference between the two?
7. Describe the reproductive processes and the development of the egg in *Hydra*, and contrast therewith the modes of reproduction observed in *Vorticella* and *Amoeba*.

SHEET XVII.

1. HYDRA. A., feeding at ease. B., alarmed and retracted.
ps. t., hypostome. *t.*, testes. *ov.*, ovary.

2. Section of body. *ar.*, archenteron. cp., Sheet XX., Fig. 6.

3. Hydra budding.

4. A colonial Hydrozoon

5. Ovum and spermatozooids

6 and 7. Enlarged section, transverse and longitudinal, to show constituents of wall.

ECTODERM; *ee.* and *m. t.*, muscle tail cells *in.*, interstitial cells
ne., undischarged, and *ne'*, everted nematocyst.

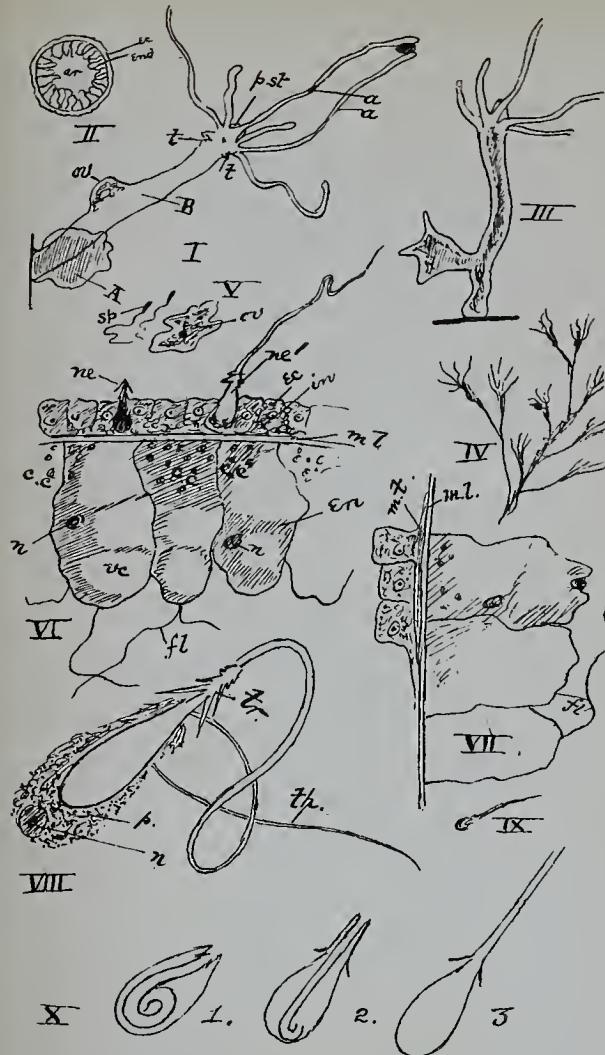
MIDDLE LAMELLA, *m. l.*

ENDODERM, *en.* *c. c.*, chlorophyll corpuscles. *n.*, nucleus. *v.*, vacuole,
 and *fl.*, flagellum.

8. Nematocyst. *tr.*, portion of trigger. *th.*, thread. *p.*, protoplasm, and *n.*, nucleus.

9. Small nematocyst such as occur in batteries in the arms.

10. Diagrams to illustrate eversion of a nematocyst.





THE FRESH-WATER MUSSEL.

§ 1. The fresh-water mussel (*Anodon*) is a bilaterally symmetrical coelomate metazoon, with musculature, nervous system, circulatory, respiratory, and excretory apparatus differentiated. This predicate might also be used to express a vertebrated animal. But we shall find as we proceed that the mussel has these sets of organs arranged according to a plan entirely different from that of the vertebrate. We are on an altogether different line here. The mussel is an example of the plan of structure found in the great division of the **Mollusca**. This plan differs most profoundly from the vertebrate plan; and if vertebrate and mussel have a common ancestry, their pedigrees most certainly have diverged since an almost inconceivably remote past.

§ 2. The **shell** of the mussel displays a straight hinge line marking the dorsal middle line, a rather blunted *anterior* end, and a sharper *posterior*. The valves of the shell are right and left. Each valve is marked externally by concentric lines of growth around its first commencement, or *umbo*. It consists of organic matter indurated by carbonate of lime, but at the margin a fringe of uncalcified substance (*periostracon*) ensures the effectual closing of the shell. The inner aspect of the shell is marked by *muscle impression* (*infra*) and by a *pallial line*, along which the mantle is attached. Its valves are closed by powerful *adductor muscles*, against which an *elastic ligament* along the hinge line works. After death the adductors relax and the shell yawns open.

§ 3. On removing the shell a fleshy flap, the **mantle**, is seen to be closely applied to its inner surface. It is by the external secretion of the superficial epithelium of this

mantle that the shell grows. The edge of the mantle, where growth is most active, is thickened. There are right and left flaps, corresponding to the valves of the shell. They do not unite posteriorly or along the mid-ventral line.

§ 4. By cutting away the mantle as in Fig. 4, the actual ventral portion of the body is seen. Antero-ventrally is the muscular **foot**, and postero-dorsally to this the soft **visceral mass** containing the alimentary canal. The latter is largely hidden by the two (inner and outer) **gill plates** (of the left side in the figure). Traced back, the two **gill plates** of the left side are found to coalesce behind the visceral mass with those of the right, dividing the posterior opening into an upper *exhalent opening* or *cloaca*, and a lower *inhalent*. We shall consider the minute structure of these **gill plates** below. It will suffice now to state that each plate is a bag-like lattice work, and consists of two layers, or *lamellae*. The external lamella of the outer gill on either side coalesces with the base of the mantle on that side. The inner lamella of the outer gill and the outer lamella of the inner unite dorsally in the *gill-axis*, and this is attached to the body in front and floats freely posteriorly. This will be understood better with the help of Figs. 1, 2, and 3, Sh. XVIII. The shaded part is the body and mantle, the black the shell. 1 is a section in the anterior part of the gill chamber corresponding to the line 1 in Fig. I. Here the gills are attached above to mantle and body, so that there are two supra-branchial sinuses (*s.b.s.*), one between the lamellae of each gill; *v.m.* is the visceral mass, *i.b.s.* the infra-branchial sinus. The next section (2) comes just behind the foot, and here a direct passage from the infra- to the supra-branchial chamber is seen. In Fig. IV. a rod (*X*) is thrust through this; it probably functions in the flushing of the cloaca. 3 shows how, behind, the gills separate the inhalent and exhalent openings. The large cilia in the gills sustain, in life, a continuous current of water from the inhalent opening into the supra-branchial chambers and out *via* the cloaca.

§ 5. The structure of the gills is complicated. Each

lamella consists of a series of longitudinal bars with transverse communications, and the superficial cells have abundant cilia. A further complication is introduced by the partial coalescence of the two lamellae of each gill by means of inter-lamellar junctions. Fig. II., Sh. XIX., shows transverse sections of the gill plates. The finger-like outlines are the longitudinal bars in transverse section, and they are seen to be joined by horizontal connections. The inter-lamellar junctions of the outer gill are the bars of tissue containing the blood space (*b.v.*). The two lamellae (*e.l.* and *i.l.*) of the outer gill (*O.G.*) are evidently much less closely united than those of the inner (*I.G.*), where the inter-lamellar union is evidently as abundant as the transverse. It is in the space of the outer gill of the female that the ova undergo their development into the larval mussels, or *Glochidia* (*infra*). The glochidia appear to the naked eye as reddish grains distending the gill.

§ 6. Owing to the lamellar character of the gills, the mussel is placed along with the great majority of other bivalves (oyster, cockle, scallop, *e.g.*) in a distinct division of the Mollusca, the **Lamellibranchiata**.

§ 7. The urinary and genital openings occur close together on either side. They open into the inner suprabranchial chamber above the inner gill. Hence in dissection it is necessary to cut off the greater portion of both gills, and to separate the two lamellae of the inner gill at its base near the anterior ends to expose them (Fig. V., Sh. XVIII.).

§ 8. At the side of the visceral mass in front of the gills are two triangular flaps, roughly resembling them in superficial appearance, but not in histological structure, the *labial pulps*. These run round to the opposite side in front of the foot and behind the anterior adductor, and the mouth opens in the middle line between them. The course of the **alimentary canal** is fairly simple. There is a short oesophagus (*oes.*), a stomach (*st.*), into which the ducts of a dark-green digestive gland (visible from the exterior) open.

An intestine (*int.*) follows, forming a complicated loop (figured) in the visceral mass, and terminating in a *rectum* (*r.*) running along towards the dorsal middle line through the pericardial cavity and embraced by the ventricle, and opening by an *anus* dorsal to the posterior adductor. The food consists of small organic particles in suspension, and is brought in by the respiratory current.

§ 9. The **body cavity** is almost entirely obliterated in the visceral mass by the genital gland. Its dorsal portion remains, and is spoken of as the *pericardium*. In the Vertebrata also the pericardium is a part of the coelom cut off, but here the resemblance ceases. The genital glands, or *gonads*, are very similar in both sexes, consisting of branching tubuli. In those of the female having a distinct duct, and in the ova not being shed into the body cavity, we have a departure from the common arrangement in Metazoa. In most Metazoa, as in Vertebrata, the ova dehisce into the body cavity, and are then caught up by the oviducts. Among our types we note another exception to the same rule in the crayfish. A number of microscopic blind pits, opening into the dorsal side of the pericardium, and apparent to the naked eye as a reddish streak, constitute the *organ of Keber*.

§ 10. The **renal organ** is also spoken of as the *organ of Bojanus*, and as the *kidney* or *nephridium*. The last term is perhaps preferable. It is a paired structure, and lies along on either side of the floor of the pericardium. Its structure will be understood by imagining a straight tube bent simply once upon itself. The two openings of the tube would then be brought close together. Conceive the bend placed against the posterior adductor, and the two openings against the part where the intestine bends posteriorly to form the rectum. Now let the upper end of the bent tube be twisted a little down and out to form the external opening of the nephridium, and the lower opening twisted up to open into the body cavity (*cp. Fig. I. a, Sh. XIX.*). The lower tube is lined with dark glandular tissue, and forms the urinary secretion; the upper is thin-walled

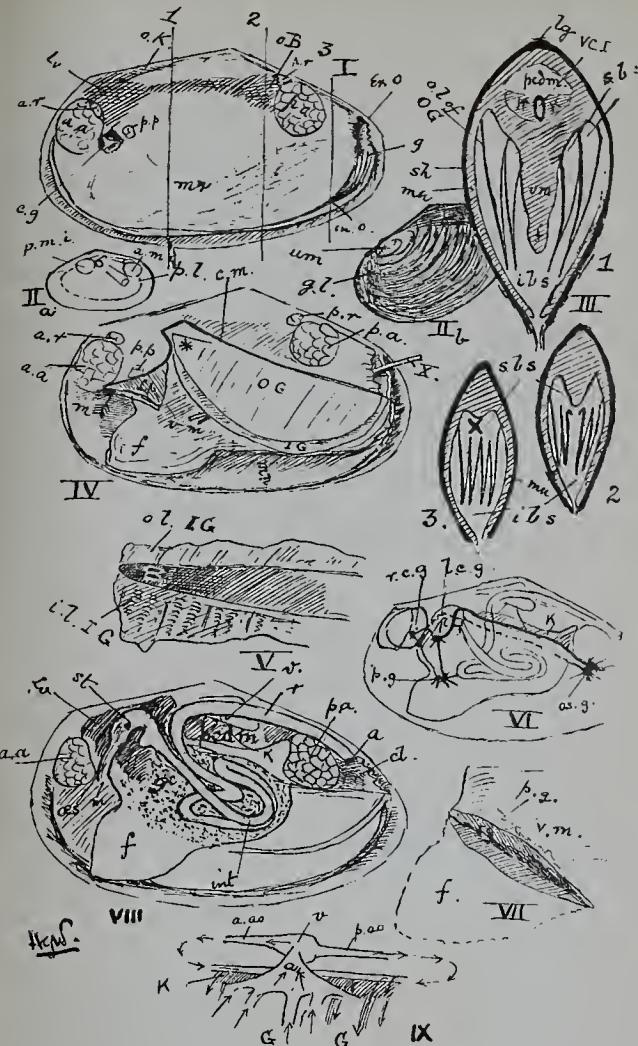
SHEET XVIII.

MUSSEL.

1. Mussel, shell removed.
2. a. and h., inner and outer views of shell.
3. Sections at the points marked in 1 by vertical lines.
4. First stage in dissection, the mantle removed. X, a rod thrust from infra to supra branchial chamber through the opening shown in III., 2.
5. Second stage in dissection, gills removed to show renal opening and gonad-pore.
6. Diagram of the nervous system.
7. Foot split for the pedal ganglion. v. m., visceral mass.
8. General dissection of the alimentary canal.
9. Diagram of the circulation.

Lettering of the figures. a., anus. a. a., anterior adductor muscle. a. r., anterior retractor muscle. a. m. i., anterior muscle impression. a. ao., anterior aorta. au., auricle. e. g., cerebral ganglion. ex. o., exhalent opening. f., foot, its position indicated by dots in 7. g. l., growth lines. G., gills. i. l., inner lamella. I. G., inner gill. i. b. s., infra branchial space. lv., liver. k., kidney. mn., mantle. m., mouth. o. l., outer lamella. o. K., organ of Keber. o. B., organ of Bojans. O. G., outer gill. os. g., osphradial ganglion. p. g., pedal ganglion. p. p., protractor pedis muscle. p. r., posterior retractor muscle. p. a., posterior adductor. pedm., pericardium. p. l., pallial line. s., supra branchial space. um., umbo. v. m., visceral mass.

To face page 112.





and flabby, and is called the *ureter*. A fourth complication is introduced by the walls of the *ureters* on either side being approximated and then perforated to form an open communication, the *inter-renal opening* (*i.r.o.*). The communication between the secretory part of the kidney and the pericardium is called the *reno-pericardial pore*, or *nephrostome* (*a*). Compare the more realistic figure, I. *b*, and the text thereto.

§ 11. The central organ of the circulatory system is the heart. This has a baggy *ventricle* wrapped closely round the rectum, and receiving blood through a pair of *auriculo-ventricular* valves from the two triangular membranous *auricles*. Two main arteries run out of the ventricle, an *anterior aorta* dorsal to the intestine, and a *posterior aorta* ventral to the rectum. The blood, after circulating through the system, returns by a series of lacunar spaces to a central *vena cava* between the kidneys; thence it flows through the kidneys to the gills, and thence to the auricles again, the bases of which are applied to the gill axes. The respiratory activity of the gills is perhaps not so important as it would appear. The blood must also be aerated very considerably in the mantle, and it returns thence by a special vessel direct to the auricle, without passing to *vena cava*, kidney, or gill (*cp. Fig. IX., Sh. XVIII.*).

§ 12. The nervous system consists of three pairs of ganglia, in all cases conspicuous reddish-orange bodies connected by nervous threads, the commissures. The *cerebral* ganglia (*c. g.*) lie at either side of the oesophagus, are widely separated, and communicate by means of a *supra-oesophageal commissure*. The two *pedal ganglia* lie in the visceral mass just dorsal to the anterior part of the foot. The *osphradial ganglia* are closely apposed and lie ventral to the posterior adductor muscle. There are numerous sense papillae on the lips of the inhalent opening—probably olfactory.

§ 13. Evidently we have in this metazoon an entirely different plan from that of a vertebrated animal. All the fundamental vertebrate features of a tubular nervous system (*i*), pharyngeal gill slits with hypoblastic gills (*ii*),

notochord (iii), portal circulation through the chief digestive gland (iv), division of body muscles into myotomes (v), are not represented even by a rudiment or a vestige. Where the two types have the same kind of organs they have them only to differ. In the vertebrate the heart (in the embryo or always) sends *venous* blood from behind forward to the respiratory organ. Here the heart is *arterial*, and receives blood from the respiratory organ on either side to send it anteriorly and posteriorly. Here there is no well-marked head, nor paired limbs, nor any visual organ. (An extremely small auditory sac [otocyst] lies postero-externally to the pedal ganglia on either side.) The skeleton (shell) is an *external secretion* of the epiblast, while that of the Vertebrata is chiefly mesoblastic.* The oxygen-carrying red corpuscles and haemoglobin are absent from the blood; some other unstable compound, of which some other metal may perhaps be the metallic constituent instead of iron, may serve to hold the comparatively insoluble oxygen. The coelom is greatly reduced in extent; the female gonad has a direct duct. The ventral surface becomes the muscular mass of the foot. Where the same names occur in mollusc and vertebrate, they usually indicate fundamentally different things. Thus the foot is not the distal part of a paired limb, for instance; the stomach receives the liver secretion, and is therefore physiologically more like the rabbit's duodenum. There is indeed scarcely one great structural line in common between the two plans. We cannot say even that anterior and posterior, dorsal and ventral, correspond in mollusc and vertebrate, so entirely divergent are they.

§ 14. In development the ovum of the mussel contains a certain quantity of yolk, considerably less in amount than in the frog. The arrangement is *telolecithal*, as in Vertebrata. *Segmentation* is followed by *invagination*, so that up to the gastrula, the coelenterate level, mussel and vertebrate travel side by side. But the blastopore is not in

* Note, however, that in the enamel of the placoid scales and teeth we have an epiblastic element; but the enamel is not a *secretion*, but formed by the *modification of cells*.

the direction of the anus, *but closes along the ventral middle line*. The meoblast appears as solid masses which split to form the coelom. The nervous system is epiblastic, and the other sets of organs are derived from the same embryonic layers as in the Vertebrata. The divergence of the development is only what the divergence of the adult anatomy has led us to expect. And the reader will be also prepared to hear that in the most ancient rocks in which fossils occur the Mollusca are almost as distinctly marked off from the Vertebrata as they are to-day.

§ 15. The ova develop into small molluscs (*glochidia*), at first very different from the parent. One is figured on Sh. XIX., VI. They have only one adductor muscle, which becomes the posterior one in the adult, and the intestine is spirally coiled. Each shell valve has large recurved teeth, and the glochidium is moored by a long adhesive filament, the byssus (*b.*). The ova are discharged from the genital opening into the supra-branchial chamber above the inner gill; they then pass back to the cloaca, and thence by the outer supra-branchial to the outer gill, where they are fertilised by spermatozoa brought in by the inhalent current. The glochidia are retained in this "brood pouch," the outer gill, until a stickleback or other suitable fish approaches the mother. They are then discharged into the water, and some may have the good fortune to attach themselves to the epidermis of the fish by the valve teeth. From this they drop later in a new locality to complete their development. This temporary attachment secures the distribution of the young mussels up stream as well as down, and insures them against the danger of being washed out to sea—a danger to which all fresh-water larvae are liable.

§ 16. We would call the attention of the student here to the vast multitudes of *glochidia* to be obtained from one mussel. Very few of these, one perhaps in many thousands, will reach the adult state. There is necessarily a direct connection between the security of the offspring of animals and their number. The frog resembles the mussel in this

matter; a million ova are eaten, or perish half developed in the tadpole stage, for a mere handful that complete the object of life and attain sexual maturity. Compare, on the other hand, the bird, hatching most of the eggs it produces, and protecting its offspring, so that perhaps in some cases as many as a quarter reach the adult stage. The minimum of reproductive activity with the maximum of individual security is perhaps to be met with in the case of man or some other of the higher mammals, but even here there is still a quite sufficiently high proportion of merely accidental, aimless, and abortive births. For instance, in England, of every ten children born alive, only seven live to the age of fourteen.

The comparative anatomy of the mussel would be more clearly understood if the snail were also studied by the student, but at present the latter type is not required of London University students in their first science examination, and we reluctantly omit it. Both types are dealt with in *Lloyd Morgan's Animal Biology*, and there is a full account of the various developments of the molluscan type in the "British Encyclopædia" article, *Mollusca*.

SHEET XIX.

MUSSEL

1. a., Diagram of the pericardial cavity. b., actual dissection, auricle removed, ureter opened up in two places and the secretory part also opened posteriorly. a., an arrow through nephrostome into s. p. n., the secretory part of nephridium. r. f., retractor of foot (p. r. in Sh. XVIII). A., slip of paper lying in ureter. b., an arrow through the opening of the secretory part in the ureter. i. r. o., inter renal opening. c. o. e., cerebro osphradial ganglion.

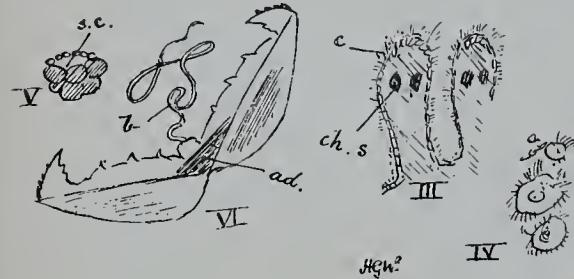
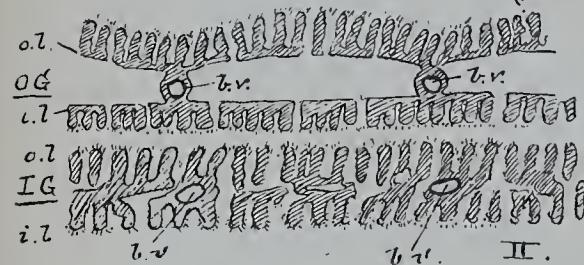
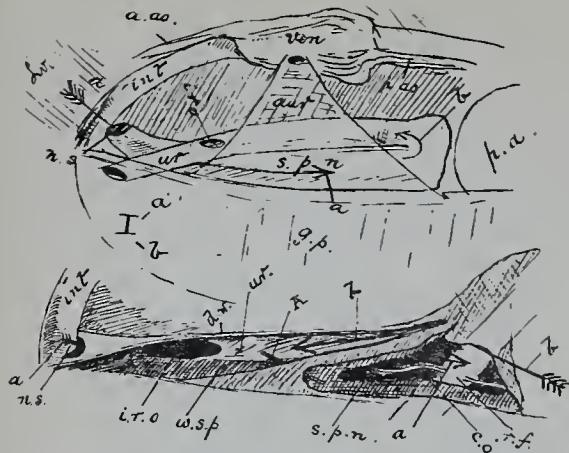
2. Transverse section of the gills. b. v., blood vessels.

3. Enlarged fragment of gill to show cilia and chitinous supports.

4. Ciliated cells.

5. The Blastosphere stage in development.

6. Glochidium with its single adductor (=posterior of adult) and its byssus thread.



Questions on the Mussel

1. Describe the alimentary canal and the generative organs of the fresh-water Mussel.
2. Describe the circulatory, respiratory, and excretory organs of the fresh-water Mussel.
3. Draw diagrams, with the parts named, of the central nervous system and renal organs of (a) *Lumbricus*, (b) *Astacus*, and (c) *Anodon*. (d) Compare *Lumbricus* and *Anodon*, in respect of their nervous systems; and (e) *Astacus* and *Anodon*, in respect of their renal organs.
4. Describe the renal excretory and the reproductive organs of the Mussel, the Earthworm, and the Frog.
5. Give an account of the sexual organs and the early development of the *Anodon*.
6. Describe in detail the gill of a Mussel. What are the functions of the gills?
7. Give an account of the body cavity of the Mussel, and compare it with that of any vertebrated type (say which you take).

THE EARTHWORM.

§ 1. The earthworm (*Lumbricus*), like the mussel, is an isolated type among these we study. Its nearest relation among these is, probably, the mussel, but their connection is very remote. We have here the plan of structure common to the great division of the *Chaetopoda*. The earthworm is a bilaterally symmetrical, coelomate metazoon ; but it differs most strikingly from the mussel in its marked **metameric segmentation**. This term we have defined (Part I., Ch. IX.) as the repetition of similar parts along the main axis of the animal ; and we have noticed it in the vertebral column, visceral arches, vascular arches, limbs (?), myotomes, and segmental tubuli of the true Vertebrata. The metameric segmentation is here marked even externally, the earthworm being evidently a chain of rings (somites). The anus is terminal and posterior. The mouth, at the anterior extremity, is overhung by a preoral lobe (*p.o.*), containing the cerebral ganglia. The worm has no paired limbs (*cp.* Vertebrata and Crayfish), and its ventral surface is not thickened to form a muscular foot, as in the mussel. It progresses by means of spike-like secreted structures of a horny substance known as *chitin*, the *setae* ; of which there are eight, in four groups of two each, to each somite. These can be felt as a roughness along the ventral surface, and their rows seen as four faint double lines (see figure).

§ 2. The anterior portion of the body is distended by the reproductive apparatus ; and from the twenty-ninth to about the thirty-fifth segment the body wall is highly glandular, forming the *clitellum*. The excretory apertures occur, a pair on each somite, behind the first four. There is a pore, the *dorsal pore*, in the groove, between each somite on the dorsal middle line. The worm is hermaphrodite,

though not self-fertilising. The male apertures occur—they are usually rendered conspicuous by tumid lips—on Somite XV., the female on XIV.; two other pairs of apertures, the anterior and posterior spermathecae, come between IX. and X. and X. and XI. respectively. Their function will be understood later. A secreted *chitinous cuticle* is easily removed from the dead worm; it is opalescent and semi-transparent. It is formed by the underlying *hypodermis*, a layer of imperfectly separated cells, one cell only in thickness. In the hypodermis there also occur unicellular glands resembling goblet cells. If the reader compares this epidermis with that of the vertebrate, he will see that in the two precisely the same ends are served by very different means. We have in both cases—

- (i) An insensitive, dead, protective layer;
- (ii) A living layer underneath.

But in the Vertebrata (i) consists of successive strata of *dead cells*, the *stratum corneum*, while in the worm it is a *secretion*; and (ii) the living, active layer in the Vertebrata is stratified.

§ 3. The alimentary canal of the worm is a straight tube with no loops or coils. The mouth opens into a highly muscular pharynx, which passes into an oesophagus (Somites V. to XVIII.). There open into this six glands in segments eleven and twelve, the *calciferous glands*.* Next to the oesophagus comes a thin-walled crop, then a muscular gizzard, and then a straight intestine, the wall of which is inturned dorsally to form a hanging longitudinal flap, the *typhlosole*, which increases the absorbent area. The worm feeds by passing large quantities of soil through its body and extracting the nutriment contained therein. Besides the calciferous glands (the alkaline product of which probably neutralises the organic acids of the soil) no conspicuous digestive gland opens into the canal. The whole hypoblastic epithelium is highly glandular. No region of it, however, has given up the absorbent part of

* Marshall and Hurst state that only two of these open to the oesophagus.

the work and become specialised for secretion, as is the case with the secretory epithelial lining of the liver diverticulum * in mussel, crayfish, and Vertebrata. Of course, here the terms "crop," "gizzard," "oesophagus," "pharynx," indicate no homology with the similarly named parts in Vertebrata. They indicate simply a supposed resemblance in physiological importance.

§ 4. Along the dorsal side of the intestine is a quantity of yellowish tissue, the **vasifactive tissue**. It was formerly styled liver tissue, but it probably has no connection with digestion or excretion, though it may play an important part in the work of the elaboration of the nutritive fluid. In the earthworm the nutritive and respiratory functions, which in the Vertebrata are both discharged by the blood (*cp. § 34, Part I.*), have separate fluids, the nutritive and *pseudohaemal* fluids. The **nutritive fluid** is a colourless plasma with colourless amoeboid corpuscles, like the lymph of Vertebrata, and occupies the coelom. The *coelom* in each segment of the body is almost completely separated from that in the next by a connective-tissue *septum*. The septa, however, are absent in the somites containing the pharynx. In each somite there is a direct communication with the exterior through the dorsal pore (*d.p.*), and indirectly through the nephridium. Possibly these communications have a physiological connection with the great changes of shape the worm undergoes as it extends and contracts itself.

§ 5. The *pseudohaemal* fluid is contained in a special series of vessels. As in the true Vertebrata, the medium by which oxygen is carried is *haemoglobin*. Here, however, the haemoglobin colours the plasma; it is not contained in corpuscles. There are small corpuscles in this fluid, but they are colourless. The chief vessels are longitudinal; there is a *dorsal* one, seen very conspicuously on opening the worm (Fig. III., Sh. XI.), a *supra-neural* lying above the nerve chain (which runs in the earthworm along the mid-ventral line), and an *infra-neural* beneath this. There

* Hollow outgrowth.

SHEET XX.

EARTHWORM.

1. Ventral view of worm. *eu.*, cuticle. *se., se.*, the longitudinal lines of setæ. Openings of spermathecae (*sth.*), oviduct *ov.*, and vas deferens, *v. d.*, shown.

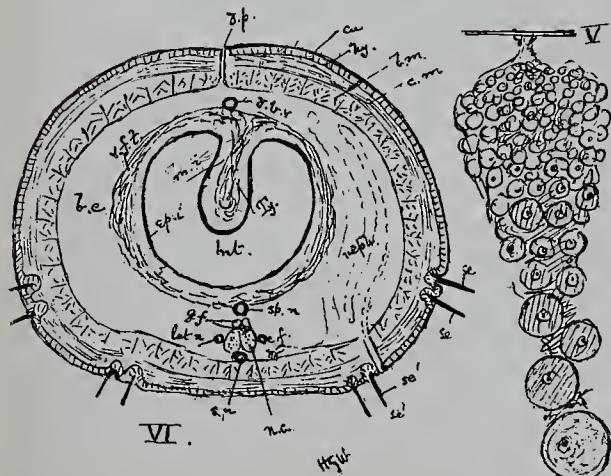
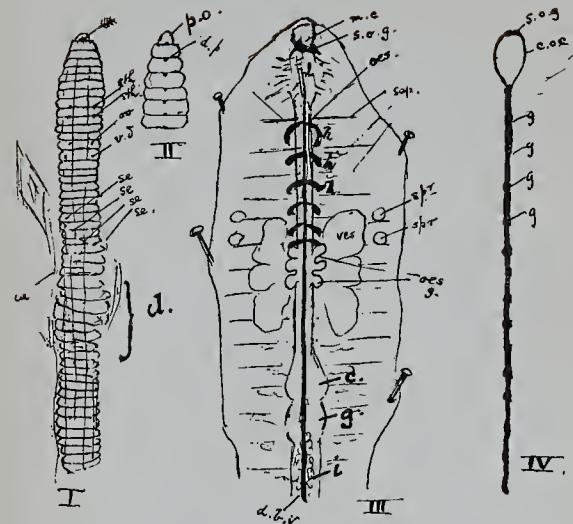
2. Dorsal view to show dorsal pores.

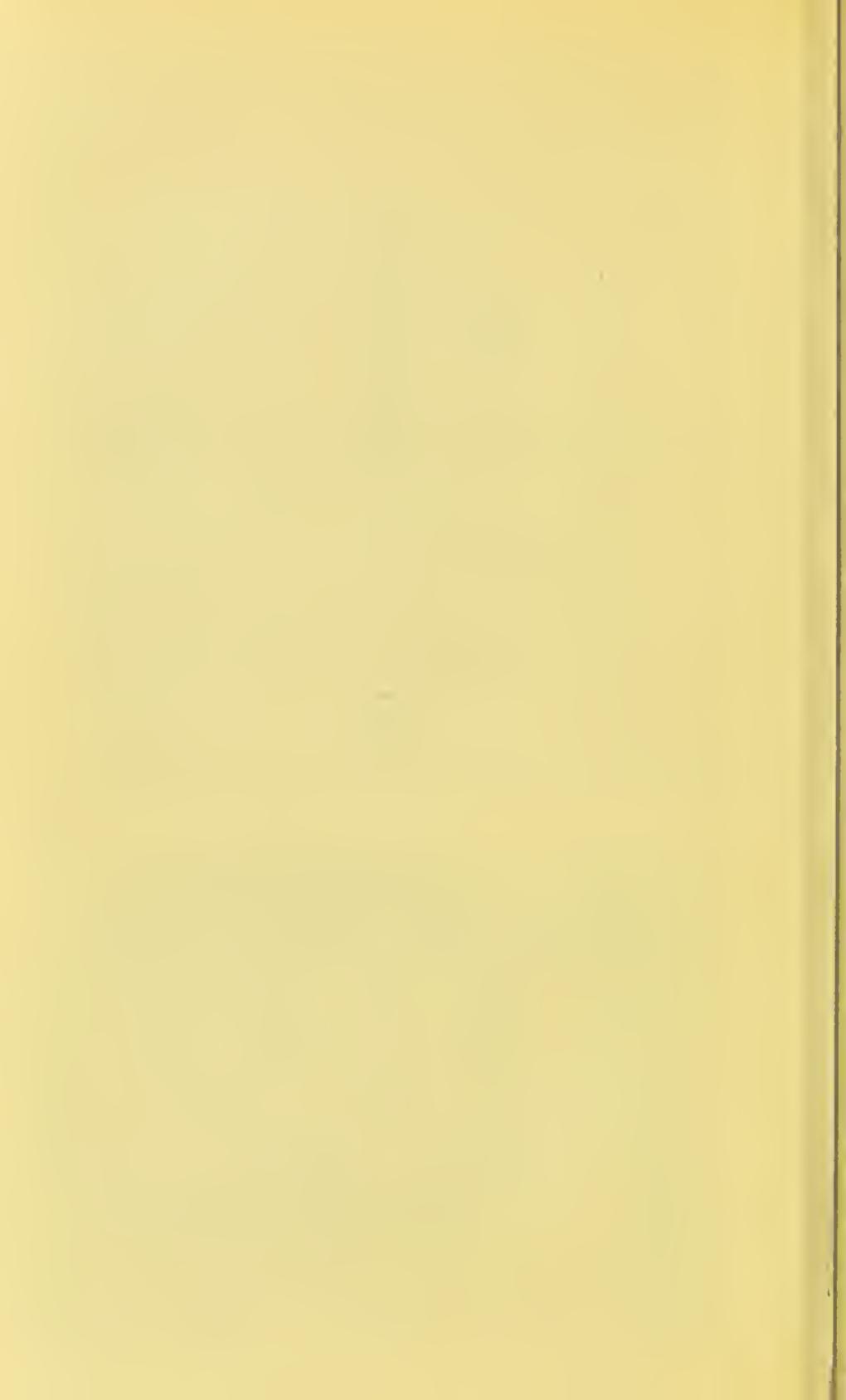
3. General dissection. *m. c.*, oral cavity. *ph.*, pharynx. *aes.*, oesophagus. *aes. g.*, oesophageal glands. *c.*, crop. *g.*, gizzard. *i.*, intestine. *s. o. g.*, supra oesoph. ganglion. *d. b. v.*, dorsal blood vessel and its hearts, *b. b.*. *sep.*, septa. *spr.*, spermathecae. *ves.*, seminal vesicles.

4. The nervous system. *c. o. c.*, circum oesophageal commissure. *g. g. g.*, ganglia.

5. The ovary.

6. Transverse section of worm behind the gizzard. *Ty.*, typhlosole. *n.c.*, nerve cord surmounted by its (skeletal?) giant fibres. A nephridium dotted in to the right. *e. f.*, position of its ciliated funnel.





are also two *lateral neural vessels* at the sides of the nerve chain. In Somites VI. to XI. occur contractile communications between the dorsal and supra-neural vessels, the "*hearts*." In each somite the dorsal also communicates with the infra-neural vessel, and there are special vessels to the intestine, vasifactive tissue, nephridium, and so forth.

§ 6. The earthworm has no distinct respiratory organs, gills, or lungs. The pseudohaemal vessels branch abundantly just beneath the skin, and the whole surface participates in aeration. The renal organs are the *nephridia*, two to each somite. They are long coiling tubes (Fig. VI., Sh. XXI.). Each opens exteriorly by an aperture just external to the inner pair of setae, and internally by an opening in a *ciliated funnel*, the *nephrostome*. The figure is taken from Howe's *Atlas*. The first portion of the nephridium is thin-walled, then comes a thick-walled and ciliated part, and then a short muscular and excretory part. The ciliated funnel perforates the septum of the segment in which it lies, and opens into the cavity of the somite anterior to its own. The most extraordinary value is attached by some morphologists to these nephridia. Any tube, renal in its function, and opening on the one hand to the exterior, and on the other into the coelom, is called a *nephridium*. We find a pair in the mussel; and in the Vertebrata the segmental tubuli of the developing kidney are regarded as nephridia (Part I., p. 113 and foot-note). This matter will be noticed again, when we have dealt with the genital organs of this type. Here, however, we may point out that the fact of renal organs in widely divergent animal types agreeing in the simple fact of a coelomic opening seems to point much more conclusively to some common physiological necessity, not at present understood, than to common inheritance. Yet it is largely upon the nephridia that the view that the Vertebrata are related to the segmental worms rested in the past.

§ 7. The nervous system of the earthworm consists of two *supra-oesophageal ganglia* dorsal to the pharynx, a *circum-oesophageal commissure*, and a double-barrelled *nerve*

cord running along the ventral side. Expansions called ganglia occur at intervals, but ganglion cells are not confined to these ganglia. Running along the dorsal side of the cord are three *giant fibres* (*g.f.*, Fig. VI., Sh. XX.), which have been regarded as supporting structures, but which may after all be nervous in function.

§ 8. The reproductive organs are complicated. The earthworm, like *Hydra*, is hermaphrodite; but, unlike *Hydra*, is not self-fertilising. The essential male organs are the testes, very small paired bodies attached to the posterior sides of the septa between Segments 9, 10, and 10, 11. They are covered over by the seminal vesicles in the adult, very large and conspicuous white organs, which receive the sperm cells, and in which the spermatozoa develop. (See stages in this, Fig. II., Sh. XXI.) Ciliated funnels attached to the septa between Segments 10, 11, and 11, 12, receive the spermatozoa, and ducts from these, after convolutions, unite in Segment 12 to form the *vas deferens*, which carries them to the external opening (with tumid lips) upon Segment 15. The essential female organs are the ovaries, attached to the posterior face of Septum 12, 13, and which (like the chordate ovaries) shed their ova into the body cavity to be caught up (as in chordata) by the open funnels of the oviducts. A *receptaculum ovarum* stores the ova. The spermathecae are blind sacs belonging to the female organs, and open in the grooves between Segments 9, 10, and 10, 11.

§ 9. In sexual intercourse the two earthworms attach themselves, ventral surface to ventral surface, the heads pointing in opposite directions, and with the male duct of each opposite the spermathecae of the other, which are thus filled with spermatozoa. The copulation occurs above-ground at night.

§ 10. The clitellum secretes a chitinous cocoon (similar in composition to the elastic transparent cuticle), in which the eggs are laid. When this is formed the worm wriggles backward out of it. As it passes Segment 14 the ova are discharged into it, and from the spermathecae the sperma-

tazoa received in copulation. The process of fertilisation thus occurs in the cocoon. The ends of the cocoon close through the elasticity of its substance, as it is cast off at the head.

§ 11. The essential facts of development agree with those of the mussel. The ova are telolecithal; the segmentation is holoblastic, but unequal. The blastopore closes along the mid-ventral line, and at the anterior end remains open to become the mouth. Mesoblast arises as a series of solid masses of cells (not two only, as in the mussel), the *mesoblastic somites*, which split to form the body cavity in each segment. The nervous system is here, as in most Invertebrata, a solid epiblastic ingrowth. Only one or two ova develop in each cocoon, the majority being eaten by their stronger brethren.

§ 12. The oviduct of the worm and the vas deferens are often spoken of as "modified" nephridia. The fourteenth and fifteenth segments, however, contain, in addition, nephridia of the ordinary type.

§ 13. The mussel and the earthworm, we have already stated, are probably more nearly related to each other than to any other of our types. We may perhaps in conclusion state concisely the points of relationship and difference. Both are bilateral coelomate metazoa, with (1) a telolecithal ovum, (2) ventral blastopore, (3) coelom formed by mesoblastic splitting, and (4) solid nerve system. (5) Both have no mesoblastic skeleton, but an external secretion, the basis of which is chitin. They both possess nephridia; but while the mussel has one pair, the earthworm has a metamerically repeated series. The mussel has one pair of mesoblastic masses, the earthworm a metamerically repeated series. The mussel and earthworm both have supraoesophageal ganglia and a commissure running round the mouth to a ganglion on its ventral side. This is the single pair of pedal ganglia in the mussel, but in the earthworm there is a metamerically repeated series of ventral ganglia. Peculiar to the mussel in this comparison are its complicated

gills, the differentiation of its ventral surface to form a foot, its mantle flaps, the reduction of its head, and its possession of a liver. Peculiar to the worm is the locomotion by setae and the vasifactive tissue. Contrasting strongly is the hermaphrodite condition of the earthworm, and the dehiscence of its gonads* into the coelom, with the condition of things in the mussel. Traces of worms occur side by side with the fossil shells of mollusca in the Cambrian rocks. Evidently, then, we are dealing here with a far remoter relationship even than that between the extreme Chordate types, rabbit and amphioxus.

* *I.e.*, discharge of its genital products.

SHEET XXI.

EARTHWORM.

1. The worm's reproductive organs.

MALE, *t.*, testis. *s.v.*, seminal vesicles. *v.g.*, vas deferens with its fimbriated funnels and its loops.

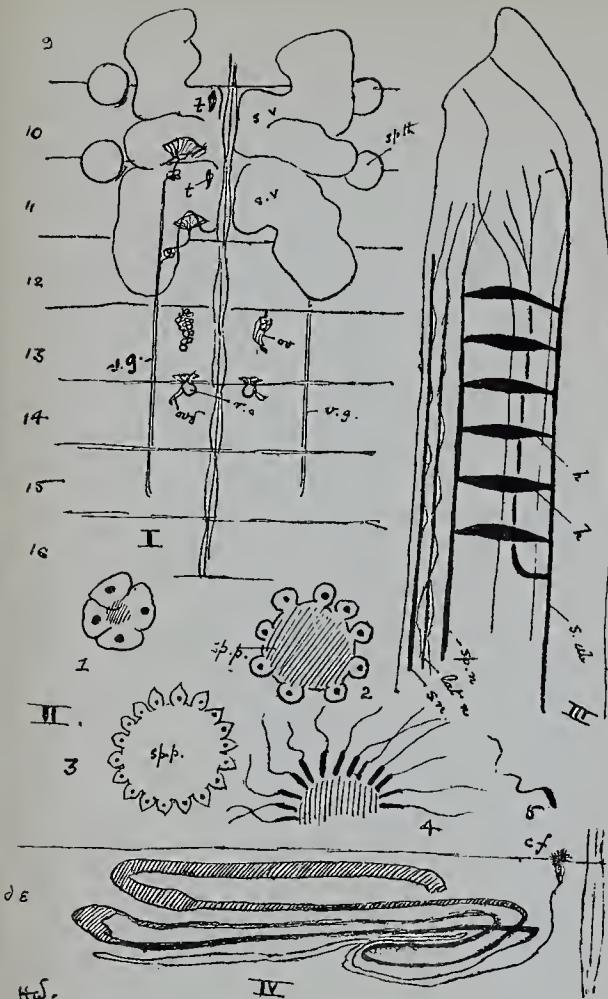
FEMALE, spermatheca, *sph.*. ovary, *ov.* *ovd.*, oviduct, with its funnel, and *r. o.*, reeptaculum ovarium.

2. Stages in the development of a spermoblast, 1, 2, (*spp.*, spermatophore) 3 and 4; 5, a spermatozoid.

3. The circulation, *s.ab.*, dorsal blood vessel. *h.h.*, hearts. *sp.n.*, supra neural; *lat. n.*, lateral neural, and *s.n.*, subneural vessels.

4. A nephridium. Compare Sh. XX., Fig. 6, *d.e.*, dorsal end of loop.

To face page 124.





Questions on Lumbricus.

1. Point out the important differences in structure (*a*) between the Amoeba and the Hydra, (*b*) between the Hydra and the Earthworm. (*c*) Briefly trace the course of development from the egg cell in Hydra and in Lumbricus, so as to show the origin of the cell layers, and the tissues and organs to which they give rise.

2. Describe the digestive, circulatory, and excretory organs of an Earthworm.

Compare the excretory organs of an Earthworm with those of a Mussel and a Crayfish, pointing out the resemblances and differences in each case;

Or, Give a short account of the mode of life of the Earthworm, more especially of the way in which it obtains and digests its food.

3. Contrast the Vascular and Alimentary systems in *Lumbricus* and *Anodon*.

4. Give an account of the structure of the vascular and nervous systems in the common Earthworm, and describe in detail its development and life history.

5. Draw diagrams of the reproductive apparatus of *Lumbricus*, giving descriptions only so far as is necessary to explain your diagrams. (*d*) Describe fully the body cavity of *Astacus*, (*e*) of *Lumbricus*. (*f*) Point out the principal features in which these two body cavities differ from one another in their relations to other organs and in any other respects.

6. Give an account, with diagrams, of a transverse section of a Hydra and of an Earthworm. Describe carefully the cell layers and the cavities present in each case, and contrast them with one another.

7. Describe fully (*a*) the central nervous system, (*b*) the notochord and its sheath, of *Amphioxus*. (*c*) Compare the central nervous system of *Amphioxus* with the central nervous system of *Lumbricus*.

THE CRAYFISH.

(*Astacus fluviatilis.*)

§ 1. The crayfish is a type of that group of Invertebrata called the Arthropoda, and distinguished by the possession of numerous pairs of many-jointed limbs. According to human standards, it is a highly developed animal. It is free-living, inhabiting holes in the banks of streams and rivers, and crawling over the bottom in search of food. It has well-developed eyes, auditory and olfactory organs, and displays considerable choice and initiative in its actions. In its forceps or nippers the crayfish has an efficient prehensile organ. It displays strong sexual desires, and the mother crayfish shelters the ova for a considerable portion of their development. Taking indications of mental activity and versatility as our standard, the crayfish is far in front of amphioxus, and the equal of many fish. It can live for a considerable time out of water, the gills being protected by a gill cover from evaporation.

§ 2. In its having limbs, a fairly distinct head, and paired sense organs, we have resemblances to the vertebrate model; but these resemblances mark no common ancestry. They are the consequences of the similarity of the mode of life. As we proceed to study the anatomy of this form, we shall see clearly that its plan is fundamentally different from that of the Vertebrata. To such resemblances arising through similarity of cause, and not through community of ancestry, the term *homoplasy* is applied. Other more familiar and more striking instances of homoplasy are the resemblance of the fore limbs of birds and bats, the fish-like build of the whale (a mammal), and the general resemblance of the Tasmanian wolf (a marsupial) to the dog.

§ 3. The crayfish occurs abundantly in many English

rivers—in the Thames, for instance—and also in those of France. The English crayfish, however, are usually a uniform brown colour, while the French are often remarkably variegated, being grey, French grey, sea green, and pale golden-brown. Seen from the dorsal side (Fig. I., Sh. XXII.), we observe in front a continuous *cephalo-thoracic shield* the “head” part of which is marked off from the “thorax” by a *cervical groove* (*cv. g.*).^{*} Two longitudinal grooves, posterior to this, mark off the *tergum* (*tg.*) from the gill covers, or *branchiostegites* (*br.*). Behind the cephalothoracic shield come six somites and a tail fin, forming the *abdomen*.

§ 4. The branchiostegites cover over the gills in a *gill chamber*. The relation of this chamber (*G.C.*) to the body is seen in Fig. III. The gills are highly vascular outgrowths of the body wall, covered with epiblast, as are the gills of the mussel and the external gills of the tadpole, not hypoblastic, like the gills of a fish or the tadpole’s internal gills. In Fig. III. *ap.* is the base of a leg, *st.* the sternum or skeletal part below the limbs, and *end* the *endophragmal vesicles*, ingrowths from the external skeleton to which muscles are attached; *tg.* is the tergum or roof part, *br.* the branchiostegite, and *ep.* the epimeron or inner wall of the gill chamber. Fig. IV. is a section of one of the abdominal somites. Hence there is no gill chamber. The letters have the same value as before, but the branchiostegite is here represented by the *pleuron* (*pl.*).

§ 5. In the ventral view (Fig. II.) we see the many-jointed appendages. These occur in pairs. In front we have the *antennule* (1), consisting of a basal part, the *protopodite*, and two small branches. Behind this is (2) the *antenna*, consisting of a basal part, the *protopodite*, a spear-shaped blade, the *exopodite*, and a many-jointed, whip-like

* Head and thorax, we need hardly say, are not equivalent to vertebrate head and thorax. The excretory organ and most of the so-called stomach are in the head, the liver and mesenteron in the thorax.

feeler, the *endopodite*. Around the mouth come (3—8) six pairs of appendages, covering one another over, which tear the food, and which are described below. Next (9) are the large *forceps*, of which the last joint but one, the *propodite*, has its outer corner produced up to form a pincer with the last (*dactylopodite*). Four pairs of walking legs (10—13) follow, of which the first two are "chelate" (that is, terminate in "nippers"), like the forceps. Each of these consists of seven parts, a *coxopodite*, *basipodite*, *ischio-podite*, *mesopodite*, *carpopodite*, *propodite*, and *dactylopodite*. Each somite of the abdomen has a pair of appendages, except the first in the female, which may have only one rudimentary one, or neither. In the male the first pair of abdominal appendages are simple scroll-like structures used in copulation. The remaining abdominal appendages, except the last, consist of a basal *protopodite*, a small *exopodite*, and a larger *endopodite*. The last has the same parts, but they are very much larger and flattened, and, together with the median telson, forms the tail fin. Commonly, the crayfish crawls about upon its walking legs, but if suddenly startled it flaps the whole abdomen forwards, and so shoots backward with considerable velocity by means of this fin.

§ 6. Each abdominal somite of the crayfish consists of tergum, pleuron, epimeron, and sternum, and a pair of appendages. In the thorax there is a distinct sternum (*st.*, Fig. II.) to each pair of appendages, and the last one is movable. Hence it would seem that the cephalo-thorax is to be regarded as equivalent to a number of somites like those of the abdomen fused together. There are thirteen such somites apparently. The eyes are mounted in jointed stalks (*E.*, Fig. IX.), and may represent another pair of appendages, in which case we have fourteen; but the general feeling among morphologists is against this view. The telson (*tel.*, Fig. I.) may, or it may not, represent one or more somites without appendages. From this we conclude that the crayfish is derived from a form which, like many of the living lower crustacea, had nineteen or more distinct somites, by a concentration of the anterior somites to form a head.

§ 7. It was pointed out long ago that all the appendages of the crayfish may be regarded as having been modified from some such form as we have indicated diagrammatically on (Sh. XXII.). In this typical form we have a basal part, the protopodite; two many-jointed branches of this, the exopodite and endopodite nearer the middle line; and a part turning away dorsalward, and typically bearing a gill, epipodite. These parts are indicated in the figures of the mouth appendages by distinctive shading. The *mandible* is the foremost of these, and consists of a protopodite, and what (to judge from the maxillipeds, *q.v.*) is an endopodite. Then comes a small *first maxilla*, and then a large *second maxilla*. The outer part of the *second maxilla* is a large flattened plate, the *scaphognathite*, which works in the mouth of the gill chamber, and maintains the respiratory current of water over the gills. Behind this comes the first, then the second, then the third *maxilliped*. The latter displays a small exopodite, a many-jointed endopodite, an epipodite bearing a gill, and a two-jointed protopodite. It is easy to see that the same parts are represented in the second and first maxilliped with a relative diminution of the endopodite, and from that to pass to the second maxilla, and recognise that the scaphognathite equals the exopodite + the epipodite. The third maxilliped also elucidates the anatomy of the walking limbs. Evidently, in these, ischiopodite + meropodite + carpopodite + propodite + dactylopodite = the five-jointed endopodite of the third maxilliped, and coxopodite + basipodite = the two-jointed protopodite. Hence we infer that the exopodite is absent in the case of the forceps and the other ambulatory limbs. The abdominal appendages are devoid of any epipodite. All these limbs should be carefully removed from an actual specimen, compared with our diagrams, and drawn.

§ 8. From the second maxilliped to the fourth walking leg (*i.e.*, XII.) each epipodite bears a gill, which is spoken of as a *podobranch* (Fig. VII., Sh. XXII.). Each podobranch consists of a plume, and a lamina folded upon itself, with the edge of the fold pointed forward. Each succeeding podobranch fits into the V-like space in the

lamina of its predecessor. Internal to each of these gills, except the first, there arises from the body wall, just at the point where the legs articulate, two rows of simple gills, the *arthrobranchia*. Each arthrobranch is shaped something like a test-tube cleaner. There is also one above the second maxilliped. The last walking leg bears no podobranch, and has no arthrobranchia at its base; but higher up above it on the body wall is a solitary gill, the *pleurobranch*, in shape like one of the arthrobranchia. Anteriorly to this are rudiments of two more pleurobranchia. All these points are easily made out on a crayfish dissected under water by removing the branchiostegite. Altogether there are eighteen gills.

Pleurobranchia.	Arthrobranchia.	Podobranchia.
First maxilliped . . .	Epipodite	
Second maxilliped . . .	Epip. + 1 . . .	1
Third maxilliped . . .	Epip. + 1 + 1 . . .	1
Forceps	Epip. + 1 + 1 . . .	1
First walking limb . . .	Epip. + 1 + 1 . . .	1
Second walking limb . " .	Epip. + 1 + 1 . . .	1
Third walking limb . " .	Epip. + 1 + 1 . . .	1
Fourth walking limb . 1		

§ 9. In the male the genital aperture is on the coxopodite of the last walking limb, in the female on that of the last but two. The renal organ (green gland) opens on a very distinct papilla on the base of the antenna. On the dorsal aspect of the basal joint of the protopodite of the antennule after removal a soft area can be felt, indicating the position of the auditory sac. This sac is filled with setae connected with ganglion cells, and small grains of sand, which perhaps intensify vibration, called the otoliths. The protopodite of the antennule consists of three joints.

§ 10. The young crayfish, like the earthworm, is covered at first by a chitinous cuticle secreted by the epidermis; but this becomes loaded in places with calcareous matter as development proceeds to form the various plates of the armour which constitute the exo-skeleton of this form. Since it is a secretion and not cellular, it obviously has no possibilities

of growth, and the growing crayfish has therefore to periodically shed this protection. This shedding is called *ecdysis*. This would be bad enough if it were only the external covering that was thrown off; but, as we shall see, it is not confined to this. What is rather misleadingly called tendon in the crayfish is also an external secretion. Tendons are here inwardly projecting parts of the exoskeleton to which muscles are attached. In the Vertebrata they consist of (mesoblastic) white fibrous connective tissue. The "gastric mill," to be presently described, is also an epiblastic secretion, and this also goes when ecdysis occurs.

§ 11. The alimentary canal contrasts very remarkably with that of the Vertebrata. In the Vertebrata, the student will remember, the length of the intestine was denoted from the mesenteron, and a very short stomodaeum and proctodaeum were turned in at mouth and anus respectively ("Biology," Part I., p. 111). In the crayfish the mesenteron remains small (it is shaded in Fig. I.), and stomodaeum and proctodaeum form the greater part of the alimentary canal. But, as in the Vertebrata, the mesenteron is the only part in which absorption goes on, and into which the digestive fluid is poured, and from which the digestive glands are derived.

§ 12. The stomodaeum (Fig. III.) consists of two parts—a short vertical tube leading from the mouth, called the *oesophagus*, and a large double bag, styled the *stomach*. Obviously this, as a part of the stomodaeum, cannot be equivalent, morphologically, to the vertebrate stomach; neither is it physiologically, since it is essentially a masticatory cavity. It is lined by the chitinous cuticle, and in this lining appear masses of calcareous matter, the "ossicles" of the gastric mill. The larger anterior portion of the stomach is called the *cardiac end*, though here it is the more remote from the heart, and the posterior part, the *pyloric*. The nature of the mill will be best understood by a study of Figs. I., II., III., and IV., on Sh. XXIII. In the middle dorsal wall of the cardiac part is a transverse ossicle, the *cardiac* (c.), having a thin broad part in front and a narrow

thicker posterior band. In the dorsal middle wall of the pyloric part is a smaller *pyloric ossicle* (*py.*). Between these, on the middle line, swing a *urocardiac ossicle* (*u.c.*) and a *prepyloric* (*p.py.*), which are mutually at an acute angle, and the latter of which is hidden on the dorsal view by the pyloric. Lateral to the cardiac ossicle are two small calcareous triangles, the *pterocardiac* ossicles (*pt.c.*), one on either side. These are joined to the pyloric through the intermediation of a lung *zygocardiac* (*z.c.*). The wall of the stomach contains circular muscle fibres, which, by contracting, approximate the cardiac and pyloric ossicles, the intrinsic muscles of the stomach. The cardiac and pyloric ossicles are connected with the dorsal body wall by bands of muscle, the extrinsic muscles, which seem to pull them apart. The alternating action of these two sets results in an alternate approximation and separation of the zygocardiacs, and the point of junction of the urocardiac and prepyloric in the middle line. The two zygocardiacs each thicken to form a *big lateral "tooth"* (*lat.t.*), and the prepyloric bears a hooked *median tooth* (*m.t.*), all three of which thus work together. Below these teeth two fringed chitinous edges project into the lumen of the stomach. These are the *strainers* (*st.*). There are two smaller strainers in the pyloric part. At the sides of the stomach two circular calcifications (the *gastroliths*) are also usually to be noticed. Behind the gastric mill is a small diverticulum, the *pyloric caecum*.

§ 13. The **mesenteron** is the only part of the alimentary canal without a chitinous lining. It receives the secretion of the so-called *liver** (Fig. I., Sh. XXIII.), and is the seat of absorption. This liver consists of a great number of yellow blind tubuli, converging on the bile duct.

§ 14. The **proctodaeum** runs straight to the anus through the abdomen. Its chitinous investment is set with minute denticulations.

§ 15. The **coelom** of the crayfish is practically non-existent.

* "Digestive gland" is a better name.

It is obliterated by a secondary series of lacunar cavities, the **venous sinuses**, which are here, as in the mussel, not definite vessels, but irregular spaces among the mesoblastic tissue. The blood is a coagulable fluid containing amoeboid corpuscles.

§ 16. The heart (Fig. V.) lies in a sinus, the *pericardial sinus* (*pcd.s.*), and consists of a polygonal, muscular, contractile ventricle, swung by bands of connective tissue in this pericardium. From it proceed, from its anterior extremity, three **arteries**, one of them median, the *ophthalmic artery*, supplying the eye stalks, and a pair of *antennary arteries* (supplying the stomach, green gland, antenna, and rostrum). From its infero-anterior lateral aspect two *hepatic arteries* run to the digestive gland. Posteriorly it gives off a median *supra-abdominal artery*, running along dorsal to the proctodaeum, and an unpaired *sternal artery*, going vertically down to the ventral middle line, and there branching into an anterior and a posterior branch, which run forwards and back the whole length of the body. The venous blood makes its way through lacunar passages to a sternal sinus on the ventral side, whence it passes by afferent branchials to the gills, and thence by efferent branchials (*e.br.*) to the pericardial sinus. It enters the heart through six valve-like openings, the ostia, two dorsal, two lateral, and two ventral, which open at the heart's diastole and close at its systole. Hence, whether they are seen distinctly or not in dissection depends very much upon the condition of the heart at the moment of its death.

§ 17. From what we have already said of the coelom the reader will not expect typical nephridia in the crayfish. The renal organs, the **green glands**, have no internal opening—there is no coelom for them to open into. They consist (i.) of a single, coiling, green secretory tube, which terminates internally in an enlargement, which may be regarded as a coelomic vestige; and (ii.) of a baggy, thin-walled collecting bladder (Fig. VIII., Sh. XXIII.), which opens out upon the basal joint of the antenna. They

further differ from the nephridia of worm and mussel in being in front of the mouth, but in early development they appear behind this, and move round it later.

§ 18. The nervous system resembles that of the earth-worm, but the ganglion cells occur only in the ganglia. It is figured on Sh. XXIII. Ingrowths of the exo-skeleton, to which great muscle bands are attached, the *endophragmal arcade* (see Fig. III.), arch over and hide the nerve cord from the infra-oesophageal to the first abdominal ganglion. These have to be carefully cut away in dissecting out the nervous system. Between the fourth and fifth thoracic ganglia the two nerve cords separate to allow the sternal artery to reach the ventral middle line. Altogether there are fourteen ganglia, one supra- and one sub-oesophageal, six thoracic, and six abdominal.

§ 19. The eye is seated upon a two-jointed stalk, which is adjustable by muscles, as is the vertebrate eyeball. It consists of a number of rod-like elements separated from each other by black pigment. Each element consists of a chitinous facet, the *corneal* facet, continuous with the general cuticle of the body; a transparent refractile rod beneath this, the *crystalline cone*; and, thirdly, what is probably the receptive nerve end, the *striated spindle*, from which a nerve fibre passes to the *optic nerve* in the eye stalk. This type of eye is spoken of as "compound," the separate elements having been regarded as each equivalent to a single eye. In all probability, however, the individual eyes do not each form a separate picture—it is inconceivable how they could; but each striated spindle records, as it were, a part in a visual mosaic, just as each rod or cone of the vertebrate eye registers its point of light in the general picture on the retina. In the development of the vertebrate eye the student will remember that the retina was not, like the sensory lining of the olfactory and auditory sense organs, derived directly from the external epiblast, but indirectly, as a hollow outgrowth, from the fore-brain vesicle. Here the entire eye, including the receptive nerve ends, is a direct epiblastic product. Moreover, here the striated

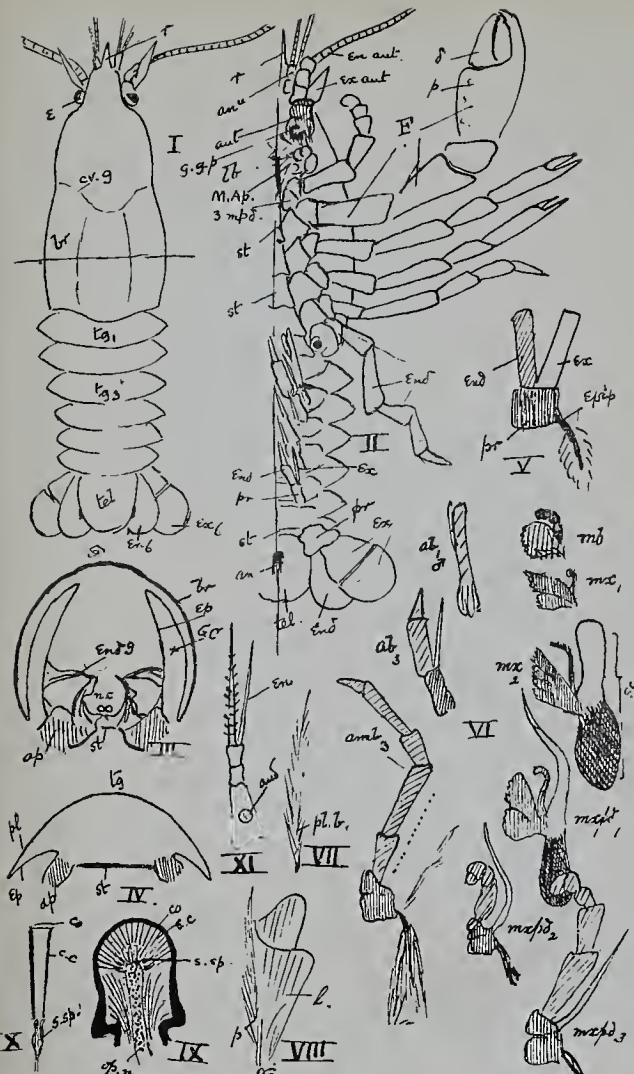
SHEET XXII.

CRAYFISH.

1. Dorsal view of Crayfish (post oral appendages not shown).
2. Ventral view, showing appendages.
3. Section through 1 along the line indicated.
4. Section through an abdominal appendage.
5. Type limb of Astacus.
6. Modification of this type in various appendages; vertical shading the protopodite; slanting, the endopodite, crosshatched, the epipodite, and unshaded the exopodite.
7. Single Pleurobranch.
8. Astrobranch.
9. The eye stalk in section.
10. Single element of eye.
11. First antenna to show position of auditory sac.

ap., base of appendage. *ant.*, antenna. *anu.*, antennule. *amb.*, ambulatory. *ab.*, abdominal appendage. *aud.*, auditory sac. *br.*, branchiostegite. *cv. g.*, cervical groove. *co.*, cornea. *c. c.*, crystalline cones. *d.*, dactylopodite. *end. g.*, endophragmal arches. *e.*, eye. *en.*, endopodite. *ex.*, exopodite. *ep.*, epimeron. *epip.*, epipodite. *E.*, endopodite. *G. C.*, gill chamber. *gas.*, gastrolith. *g. g. p.*, green gland (renal) opening. *l.*, lamella. *lb.*, lachrum. *mb.*, mandible. *mx.*, maxilla. *maxpd.*, maxilliped. *pl. b.*, pleurobranch. *p.*, propodeite, in fig. 8, plume. *pr.*, protopodite. *st.*, sternum. *s. sp.*, striated spindle. *sc.*, scaphognathite. *tg.*, tergum. *tel.*, telson.

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spindles come between the light and the nerve fibres, but in the Vertebrata the light fell through the spreading fibres of the optic nerves before reaching the rods and cones.

§ 20. The reproductive glands lie above the digestive gland and below the pericardial sinus; they are in both sexes hollow Y-shaped glands, the cavities of which are continuous with their ducts. The testis and the immature ovary are white; the ovary, however, as it approaches ripeness becomes a brownish-purple colour. The oviducts run straight to the coxopodites of the second walking leg, and are thin-walled. The vasa deferentia are greatly coiled, bright white tubes, and open on the coxopodite of the last ambulatory limb. The vasa deferentia are evidently not strictly homologous with the oviducts, since they belong to a different somite. On the other hand, they are evidently very similar structures. It has been supposed that they represent the nephridia of the thirteenth and the oviducts those of the eleventh segments respectively, which have become connected with the genital gland. The cavity of the genital gland from this point of view would really be a relic of the coelom into which the ova or spermatozoa dehisce.

The crayfish, *so far as our types go*, is exceptional among both animals and plants in its spermatozoa, which are scarcely motile at all, and in shape circular discs with radiating spokes (Fig. XI., Sh. XXIII.). The large ova are also peculiar in having the abundant yolk at the centre (*centrolecithal*), and in segmenting, as a consequence, all over the surface, but not internally. There is a gastrula stage, but the invagination is small, on account of the obstruction of the undivided yolk at the centre. The same sets of organs arise from the primary layers that we find in Vertebrata. In sexual intercourse the male fixes his seminal product upon the posterior sterna of the thorax of the female. The abdominal appendages of the female are covered by a sticky secretion, and the eggs adhere to this, the female bending the abdomen forward when the eggs leave the oviduct. The development is to a large

extent completed in this position. There are no free larval stages such as occur in the case of the crab or frog, where the yolk store is less abundant.

§ 21. We may note here, as points worth mentioning, that no cilia occur in the crayfish, and that all its muscle is striated.

§ 22. The most conspicuous features of the crayfish will incline the student to place it near the earthworm in his classification. There is the presence of chitinous cuticle, the metamerie segmentation, and especially the character of the nervous chain. He must weigh against these things, however, the absence of a coelom and nephridia, the small mesenteron, the large digestive gland, the jointed and complicated limbs, the highly organised eyes, the character of the genitalia, the gills, the essential difference of the circulation and the circulatory fluid, the absence of cilia, the striation of the muscles, the character of the genital products, and then, doubtless, a great gulf between earthworm and crayfish will open. The earthworm is very possibly more nearly related to the mussel than it is to the arthropod, in spite of the external metamerism and the suggestions of first appearances. Remote, however, as these three forms probably are from each other, they are all apparently far more nearly related among themselves than they are to any vertebrated form.

The student interested in invertebrate zoology will find that his most profitable method of study after he has mastered this book, will be the dissection of such a wider range of types as is required for the London B.Sc. degree, followed by the perusal of *Lankester's Zoological Articles*, *Rolleston's Forms of Animal Life*, or *Lang's Text Book*. He will also learn much from the issues of recent years of the *Quarterly Journal of Microscopical Science*.

Questions on the Crayfish.

1. Describe the appendages which are modified for the purposes of the mouth in *Astacus*.
2. Describe fully the circulatory and respiratory organs of a Crayfish, and compare them with those of a Mussel.
3. Describe fully the circulatory and respiratory organs of a Crayfish, and compare them with those of a Frog.
4. Describe the urinary and generative organs in (a) *Astacus*, (b) *Lumbricus*, (c) *Anodon*. (d) In what respect do the urinary organs of *Lumbricus* and *Anodon* resemble one another and differ from those of *Astacus*? (e) What is the function of urinary organs?
5. Describe the vascular systems of the Mussel, Worm, and Crayfish, and indicate the points wherein they differ in structure and function.
6. Draw diagrams of the blood vascular system of (a) *Lumbricus*, (b) *Astacus*, (c) *Scyllium*. Describe the course of the circulation of the blood in each of these animals.
7. Describe the digestive organs of *Astacus*, including the mouth appendages.
8. Describe the heart of the Frog and of the Crayfish.
9. Describe the structure of the eye and of the auditory organ in the Crayfish and in the Rabbit.

CLASSIFICATORY SUMMARY.

It may be useful to conclude this book with a brief outline of the classification of living things.

A. Organisms the greater part of whose life circles, or even the entire circles, take the form of a cell or cells invested in a cell wall (of cellulose—*cp. A. I. 3*), which do not ingest food, therefore, and which are commonly not motile.

THE VEGETABLE KINGDOM.

A. I. Vegetable organisms primarily adapted to live in water or moist situations, without vascular tissue, true epidermis, or stomata.

Thallophyta.

A. I. 1. Without chlorophyll.

FUNGI { Penicillium.
Yeast.

A. I. 2. With chlorophyll.

ALGAE { Fucus.
Spirogyra.

A. I. 3. Minute forms non-nucleated (?), reproducing by simple cell division, with cell wall not of cellulose (?).

SCHIZOPHYTA { Cyanophyceae.
Bacteria.

A. II. Vegetable organisms having a sporophore and oophore alternation of generations; the sporophore, when well developed, being specially adapted to an aerial existence, possessing stomata, epidermis, and usually vascular tissue.

A. II. 1. The oophore generation is the main plant; the sporophore is simply a stage in the reproductive process, and without vascular tissue.

MOSSES.

A. II. 2. The sporophore and oophore generations lead separate lives; the sporophore is the more important, and with distinct vascular tissue, usually arranged in the stem in concentric bundles. The male sexual elements are motile antherozoids.

VASCULAR	{	Fern.
CRYPTOGAMS		Equisetum.

Selaginella.

A. II. 3. The oophore generation lives its entire life parasitic on the sporophore. There is seed. The vascular tissue is usually in collateral bundles in the stem. There are no motile antherozoids.

PHANEROGAMS.

A. II. 3. (a) *Gymnosperms.*

A. II. 3. (β) *Angiosperms.*

(y) *Dicotyledons.*

(z) *Monocotyledons.*

B. Organisms which never display cellulose cell walls in the life circle, which ingest food, and are typically motile, and apparently always require some protenaceous food.

THE ANIMAL KINGDOM.

B. I. *Unicellular* (i.e., with no special sexual cells. The germs, however, may be "colonial").

Protozoa.

B. I. 1. Naked protoplasm. No cilia.

GYMNOHYXA—Amoeba.

B. I. 2. A cortex (and cilia).

CORTICATA CILIATA.—Vorticella.

B. II. *Multicellular.**Metazoa.*

B. II. 1. Diploblastic, *i.e.*, of epiblast and primitive hypoblast. No separate mesoblast or coelom.

COELENTERATA—*Hydra.*

B. II. 2. Mesoblast and body cavity.

COELOMATA.

B. II. 2. (α) The ventral surface is a muscular foot, there are nephridia, and a mantle.

Mollusca { Anodon.
 Snail.
 Slug.

B. II. 2. (β) Metameric segmentation, nephridia, large coelom, progression by setae.

Chaetopoda—Worm.

B. II. 2. (γ) Metameric segmentation, reduced body cavity, no evident nephridia,* jointed limbs, centrolecithal ova.

Arthropoda.

- (x) *Crustacea*—Crayfish.
- (y) *Tracheata*—Fly, Beetle.
- (z) *Arachnida*—Spider.

B. II. 2. (δ) A dorsal, *tubular*, nervous cord, embryonic or persistent hypoblastic “notochord,” embryonic or persistent gill-slits, myotomes.

Chordata. See Part I.

B. II. 2. (η) *Echinodermata*—Starfish, *e.g.*

B. II. 2. (θ) *Brachiopoda.*

B. II. 2. (ζ) *Polyzoa,*

etc., etc.

* *Peripatus*, a tracheate arthropod, has nephridia.

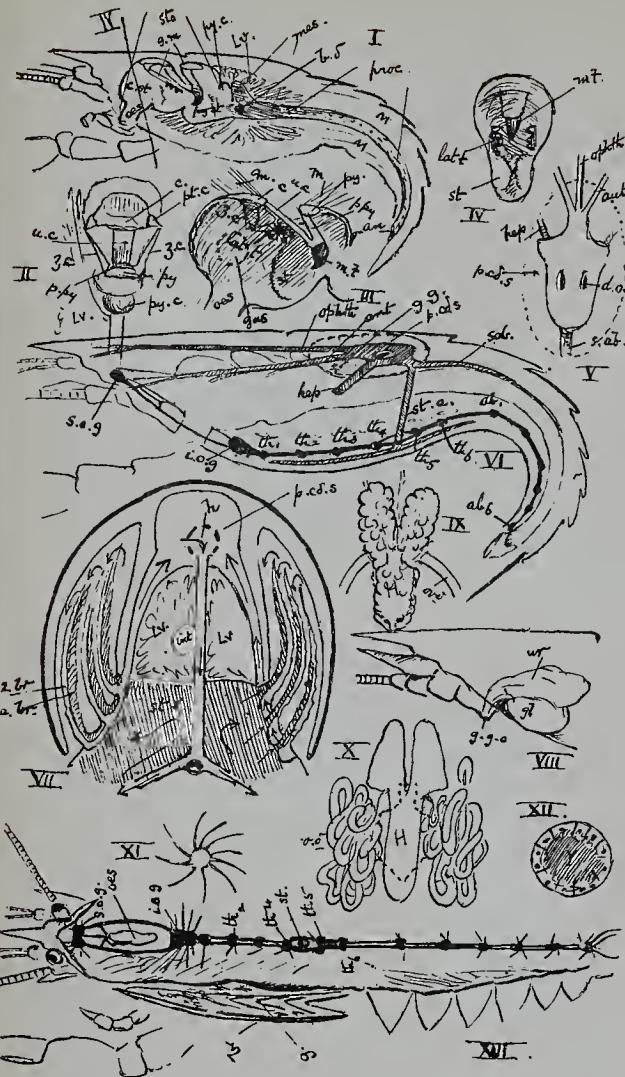
SHEET XXIII.

CRAYFISH.

1. Side view of Crayfish to show alimentary canal.
2. Dorsal view of gastric mill.
3. Longitudinal section of gastric mill.
4. Interior of gastric mill, looking into it, after cutting it across as indicated in Fig. 1.
5. Heart in the pericardial sinus.
6. Side view to show circulation.
7. Diagram of the course of the circulation.
8. The green gland.
9. The ovary and oviduct, *ord.*
10. The testes and vas deferens, *v.d.* Dotted line shows position of the heart.
11. Spermatozoon.
12. Centrolecithal segmentation.
13. The nervous system.

Reference Letters. *ant.*, antennary artery. *ab.* 1, etc., the abdominal ganglia. *abr.*, afferent branchial. *b.*, branchiostegite. *c. st.*, cardiac end of stomach. *d. o.*, dorsal osteole. *e. br.* efferent branchial. *g. g.*, position of genital gland. *g.*, gills. *g. m.*, gastric mill. *h.*, heart. *hep.*, hepatic artery. *i. o. g.*, infra cesophageal. *int.*, intestine. *lat. t.*, lateral tooth. *l. v.*, digestive gland. *M.*, muscle. *m. t.*, median tooth. *mes.*, mesenteron. *oes.*, oesophagus. *ophth.*, ophthalmic artery. *pods.*, pericardial sinns. *proc.*, proctodæum. *pt. c.*, ptero cardiac. *pyloric vesicle.* *p. pyl.*, pre pyloric. *py. st.*, pyloric front of stomach. *py. c.*, pyloric cæcum. *sto.*, stomodæum. *st.*, strainer. *st. a.*, sternal artery. *st. s.*, sternal sinus. *s. ab.*, supra abdominal artery. *s. o. g.*, supra œsophageal ganglion. *th.* 1, etc., the thoracic ganglia (six in all). *u.c.*, uro cardiac. *v. d.*, vas deferens. *z. c.*, zygocardiac vesicle.

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Miscellaneous Questions.

1. In the series of organisms (1) Amoeba, Vorticella, Hydra, Earthworm, Frog; (2) Spirogyra, Fucus, Pteris, Vicia (Bean Plant); show that the structures characteristic of the animals as such, whether high or low on the one hand, and of the plants as such on the other, are the expression of a fundamental difference in the mode of nutrition of the members of the two series.

2. Trace the progress of Histological Differentiation in the following series of organisms:—(a) *Spirogyra*, *Fucus*, Fern, (b) *Amoeba*, *Vorticella*, *Hydra*, Mussel.

3. What is the Coelom? How does it originate in the embryonic development of those animals on the University Schedule which have a coelom?

(The complete list from the schedule, "General Biology," is Rabbit, Frog, Dogfish, Amphioxus, Astacus, Lumbricus, Anodon, Hydra, Vorticella, Amoeba.)

4. What is the nature of the renal excretion? Describe the structure and exact position of the excretory organs in the Earthworm, Mussel, Crayfish, and Frog.

5. Describe the microscopical characters of the circulatory fluids met with in the Rabbit, Pigeon, Frog, Astacus, Earthworm, and Snail.

6. Describe and compare with one another by means of diagrammatic figures the structure of the Eye in (1) *Astacus*, (2) *Rana* or *Lepus*. Explain briefly the mode of action of the compound eye.

7. Describe the excretory organs of *Lumbricus*, *Anodon*, and *Astacus*. State, giving reasons for your answer, with which of these forms you consider the vertebrate excretory organs (kidneys) to be most closely allied.

8. What do you understand by alternation of generations in plants? Illustrate your answer by reference to a Fungus and to a Fern.

9. State the meaning of the terms Primary, Meristem, Secondary Meristem, Procambium, Pericambium, giving illustrative examples.

10. Is *Spirogyra* a Unicellular Plant? Discuss this question.

11. What are "*Cambial tissues*"? Where and under what conditions, and whether as transitory or permanent, do such occur in (1) a dicotyledon, (2) a monocotyledon?

12. Give a brief account, with diagrams, of the structure and modes of reproduction of *Spirogyra* and *Vaucheria*.

13. What are the *reserves* available for new growths in plants before they are in a position to absorb and elaborate food independently of such reserves? In what organs and under what forms do they occur?

14. Give an account (with diagrams) of the lowest and highest degrees of structure known to you in the Protozoa. How do unicellular animals differ from unicellular plants?

15. Describe the testes and sperm-ducts (if present) and the development of the spermatozoa in *Hydra*, earthworm, crayfish, *Anodon*, dogfish, frog, and rabbit.

16. Describe the structure of the respiratory organs and their vascular supply in *Anodon*, *Amphioxus*, the dogfish, and the frog. In the two latter instances point out the differences between the respiratory arrangements of the young and the adult form.

SYLLABUS OF PRACTICAL WORK.

It has been found most convenient to divide this syllabus into three parts. The first deals with such botanical work as is usually done in a laboratory and with the help of a demonstrator. It may be commenced after reading "The Vegetative Organs of the Flowering Plant." It is practically a sketch syllabus of the work done by the evening classes of the University Tutorial College. These classes work under considerable pressure in the matter of time, and everything is done to economise this factor. With explicit directions, plentiful blackboard illustrations, and methodical students, it is possible to get through each of the sections below in two hours; but the student must be familiar with his text-book for this to be done. The individual difference is often very marked in this work. A student working alone will take very much longer than two hours, and at the end will probably not be nearly so certain of his knowledge as one working with a teacher, to whom he can turn when in doubt. It must be understood that this part is not so much a definitely prescribed course as a sketch of what may be done. The student may substitute allied material, and alter the order of Lessons II. to VIII. as his circumstances dictate. But he should not do less than the total amount given here. The second part of this syllabus simply directs the student's attention to the garden, hedge-row, and forest as necessary accessories to his successful study. The third is concerned with the zoological types, and should be worked out fully.

In all three parts of the work the student should draw all he sees. This is of the utmost importance. So soon as we turn away from the contemplation of an object we begin to forget it, and the man who has forgotten a thing is to the unsympathetic examiner, and indeed to most practical people, as if he had never known it. It is doubtless irksome to many students to draw, but they must remember that it will be still more irksome to begin again after a failure.

PART I.

Histology.

THE following appliances are needed :—

A microscope with low power of 1 in. or $\frac{1}{2}$ in., and high power of $\frac{1}{6}$ in. or $\frac{1}{4}$ in.

A razor or microtome section knife.

A small scalpel, forceps, and dissecting needles.

A pie dish, and a few watch glasses and dipping rods.

One camel's-hair brush.

Glass slides (1 doz.).

$\frac{1}{4}$ oz. of cover glasses.

Pickle jars, and a quart of methylated spirit.

Small 2-oz. bottles containing—

Glycerine.

Alcohol.

Tincture of iodine.

Schulz' solution (= chlor-zinc iodine), $ZnCl_2$, KI and I. Stains starch and cellulose blue, protoplasm brown, lignin yellow-brown to purple, and cork red-brown.

Fehling's solution. Mix $CuSO_4$ with solution of potassium sodium tartrate in sodium hydrate.

LESSON I.

[*Material: carrot, cabbage leaf (fresh), pine leaf, which has been in spirit to extract resin, as described below.]*

In order to learn how to cut sections, take a small piece of carrot ($\frac{1}{2}$ in. \times $\frac{1}{4}$ in. \times $\frac{1}{4}$ in., say), and hold it firmly between the thumb and first finger of the left hand. Take your razor; hold it, the blade towards you, with the thumb pressed against the notch at the base of the blade, and the fingers bent over upon the back of the razor. See that both material and razor are soaking with water. Now, cutting

obliquely and towards you, shave off a thin slice of the carrot. Do not attempt to cut across the whole surface; endeavour simply to get a thin shaving of a part of it. Slide or remove by means of a brush the shaving from the blade on to a glass slide. **Do not allow it to get dry**, or it is ruined. Examine with low power. At the first attempt you will probably see a dark reddish mass of cells. Repeat this a great number of times, until the section is transparent and colourless, and evidently only one or two cells in thickness. Now put a drop of glycerine gently upon a section, and notice how much more transparent it seems. Try now to put a cover glass over this section. In doing this there is a great risk of getting air into the material. Bubbles of air appear as black spots and circles in the field, and if abundant completely spoil a section. Put on the cover glass with forceps, not dropping it flat, but at first standing it up vertically near the section to be covered, and then letting it slant down upon it. After the cover glass is on, examine with the high power. In using the fine adjustment at first, *never screw down towards the cover glass in focussing*. Focus roughly first with the coarse adjustment, go a little below the proper focus, and **screw up**.

Take the cabbage leaf, which has been soaking while the above work was proceeding in alcohol or water. Try a cross section. A difficulty arises from the flexibility of the leaf; it bends instead of being cut. The leaf may be held in a slit on a piece of carrot, and the whole mass cut transversely. Mount a good section in glycerine and examine. Cut similar transverse sections of pine leaf.

All sections not intended for permanent preservation should be mounted in glycerine, which mixes equally well with spirit and with water. Water and spirit evaporate rapidly, and a section, even a thin one, once dried up, is altogether ruined.

LESSONS II.—VII.

Stem of sunflower or bean (fresh or spirit material). Transverse section, longitudinal through bundle, and tangential for cambium.

Stem of maize. Longitudinal and transverse.

Stem of melon or cucumber (particularly good for sieve tubes). Oblique sections.

Stem of rose or any woody dicotyledon. Transverse, longitudinal, and tangential sections.

Root of pea, buttercup, or sunflower. Transverse section.

Root of bluebell.

Root of dandelion for laticiferous vessels.

Spurge for laticiferous tubes. Stain with iodine for starch.

Leaves of cabbage and grass. Transverse section in carrot, and peel off epidermis to see stomata.

Flower of daisy. Dissect with needles.

Ovary of lily. Transverse sections to see structure of ovule and embryo sac.

Seed of bean. Section; stain for starch and small aleurone grains.

Potato. Cut close under skin to see leucoplastids, a little deeper for large starch grains. Stain with Schulz' solution.

Brazil-nut. Cut section to see oil. See aleurone grains in weak and strong glycerine.

LESSON VIII.

PINUS.

All pine material should be soaked in spirit, which should be changed once or twice to dissolve out the resin. Cut wood (pine-wood matches will do) for bordered pits, and cut transverse section of the leaf on carrot. Examine male inflorescences for pollen grains, and cut autumn cones for archegonia and female prothallia.

LESSON IX.

FERN.

Transverse section of rhizome. Examine prothallium. Crush up sori and examine sporangia. Try growing point, if obtainable.

LESSON X.

FUCUS, VAUCHERIA, SPIROGYRA, PENICILLIUM, YEAST, AMOEBA,
VORTICELLA, HYDRA.

Cut conceptacles of Fucus. Examine the other types named, microscopically while alive.

PART II.

Descriptive Botany.

IN describing plants tabulated descriptions are to be avoided. In many schools printed schedules are in use, and pupils engage in a kind of scientific book-keeping, entering against each leaf, in its proper account, its insertion and composition, shape, apex, margin, venation, and surface. This is stated to greatly benefit the powers of observation, and it has an attractive simplicity; but regarded simply as an attempt to cut a royal road to luminous description, it can scarcely be called successful. This is indirectly shown by the fact that no systematic botanist ever places himself upon such a Procrustean bed in his own writings. These schedules often involve tautology, and they necessarily disregard anything exceptional, and therefore particularly worthy of notice, in the plant under description. Really vivid and accurate botanical description which can stand this test, that it should be possible to draw a recognisable figure of the plant from it, is a fine art to be acquired only after a very considerable experience. What is required of the biological student is scarcely so much as this; his descriptive exercises should be directed chiefly to secure a familiarity, which books alone cannot give, with the leading types of vegetable form. He should take care, for instance, to actually see a pod, a siliqua, a silicula, a rhizome, an ochrea, an achene, a spatulate leaf, tetradynamous stamens, and indeed all the various forms of the chief parts of a plant named in this book. He should be on the look-out for hedge-row berries, exceptional leaf forms, root-like structures, and so forth; and he should not rest satisfied if he cannot give such structures their names and morphological value. Is this structure, he should ask himself, a runner, a rhizome, or a root? Is this a berry, a drupe, or a pome? Here are

zygomorphic flowers growing, and bees visiting them : how do they work ? Only in this way can the earlier part of this book become anything more than a mere catalogue of names, a mere index to a volume of the book of Nature that still remains unread. Happily, the London University examiners in botany know how to stop this book-cramming. Questions upon descriptive and morphological points rarely figure in the written examinations, but they form now the staple of the practical one. It is not " Write down all you have got by rote about fruits," but " What fruit is this ? "

The student should try to write a few descriptions as fully as his knowledge admits. This, as we have said, is best *not* done by rule. Still, we may perhaps give a few suggestions as to how it should be commenced. In the first place, it renders a description more readable to divide it up by intervals into sections devoted to each of the great divisions of the plant structure—root, stem, leaf, flower, fruit. Each section devoted to one of these may be further broken into paragraphs dealing with its several members ; that relating to the flower may be apportioned to perianth, androecium, and gynoecium ; the compound leaf into leaf and leaflet. Again, adjectives and adjective phrases should be placed after their nouns and separated by commas. The initial word of a paragraph naming its subject should be underlined or printed and followed by a semicolon. Here is an example. The student will find it a useful exercise to attempt a sketch of this flower, based on what is here stated, as he reads this. Possibly he will recognise a familiar form.

ROOTS; adventitious from the short stem, fibrous, rather strong and fleshy.

STEM; very short, scaly, perennial.

LEAVES; radical, exstipulate, sessile, obovate-oblong (or spatulate), with pinnate reticulate venation, unequally toothed edge, corrugated upper and downy under surface.

FLOWERS; actinomorphic, inferior, in the axils of the leaves on smooth peduncles about half the length of the leaf.

CALYX; tubular, five-fid, with acuminate teeth.

CORILLA ; gamopetalous, with a tube and five flat obcordate lobes.

STAMENS ; five epipetalous, opposite lobes of corolla, almost sessile ; the *anthers* innate, introse, with longitudinal dehiscence.

OVARY ; superior, one-celled, with free central placentation, style with round stigma either reaching to throat of corolla tube or half-way down it. In the latter case the anthers are in the throat of the tube ; in the former, half-way down.

FRUIT ; a five-valved capsule enclosed in the persistent calyx ; the seeds, albuminous with a dicotyledonous embryo.

Here is another familiar plant :—

Roots ; adventitious, fibrous.

STEM ; woody, perennial, subterranean, short, scaly, sending out long weak *runners* which root at the nodes.

LEAVES ; verticillate, ternate, with long petioles, and membranous, lanceolate, acuminate stipules ; the *leaflets* nearly sessile, roundish, oblong, with pinnate reticulate venation, and coarsely serrate margin.

Flowers ; perigynous, actinomorphic, in corymbose inflorescences, with bifid herbaceous bracts.

CALYX ; herbaceous, flat ; *sepals*, free, in two whorls of five each (or rather five sepals and an epicalyx).

CORILLA ; polypetalous, white, larger than calyx, with five round petals.

STAMENS ; indefinite, filaments short and stiff, anthers cordate.

GYNÆCEUM ; apocarpous, on a central elevation of the receptacle, with filiform styles and simple stigmas ; *ovules*, solitary, ascending.

FRUIT ; a pseudocarp, the conical succulent receptacle bearing the true fruits as achenes ; *seed*, ex-albuminous.

After drawings have been made of these from these descriptions, the student may very well attempt to write one

himself. Let him get some familiar plant, root and all, and set to work. What follows is not a descriptive scheme, but merely intended as a suggestion of what to look for.

Root or Roots; tap or adventitious? If the latter, state where given off. Fleshy or fibrous? Annual, biennial, or perennial (lasting one, two, or many years)?

STEM; erect? If so, herbaceous or woody, branched or unbranched? Branches verticillate or alternate? If herbaceous, solid or fistular (hollow)? Or is it prostrate, bending up or down, or short and almost buried, or a runner, a corm, or a rhizome? Is it a climbing stem, and if so, does it climb by its own twining or by short tendrils, leaf tendrils, adventitious roots, or how? Are some of its branches spines, cladodes, or tubers? Is it conspicuously rounded, angular, compressed, or hairy? Is it scaly?

LEAF; deciduous (*i.e.*, shed at autumn) or evergreen? Alternate, verticillate, opposite (decussate), radicle? Sessile or petiolate? Stipulate, exstipulate, ligulate, sheathing (=amplexicaul)? Spiny? Dotted? *Simple or compound?*

If simple, what shape lamina? apex? margin? venation? Smooth, warted, rugose, or hairy?

If compound, binate? ternate? palmate? imparipinnate? bipinnate? biternate, etc. (§ 28). *Leaflets*, sessile or with petiolule? Shape of these, apex, margin, venation (§§ 29 to 32)?

Flowers; solitary or in inflorescences (specify kind of inflorescence)? Complete or incomplete? Perfect or imperfect? Zygomorphic or actinomorphic? Cyclic, spiral, or hemicyclic? Superior, inferior, or perigynous? If two types of flower, male and female, or sterile and fertile, describe each by itself.

BRACKETS; herbaceous, membranous, coloured? or ebracteate (without bracts)?

Any bracteoles on peduncle? Any epicalyx?

CALYX; herbaceous or coloured? Poly- or gamo-sepalous?

Special form (§ 68).

COROLLA (§ 69).

Or is there a perianth? Polyphyllous, gamophyllous?
sepaloid, petaloid?

ANDROECIUM; definite or indefinite? Number if definite?

Any special arrangement (§ 70). Filament?

Or sessile? Anthers, innate, connate, versatile?
Dehiscence, if it can be ascertained.

GYNÆCEUM; monocarpellary, polycarpellary? If the latter, apocarpous or syncarpous? If the latter, unilocular, bilocular, trilocular, or multilocular? Stigma sessile or—? Placentation, parietal, axillary, axile, free central, superficial, basal, marginal? Ovule, one or many? If microscope is handy, ascertain whether orthotropous, anatropous, campylotropous?

FRUIT; pseudocarp or true fruit (specify kind)? Seed, albuminous or exalbuminous?

After each description the student should attempt a floral diagram or formula. We have figured several of these former, from which the student will readily grasp the principles of construction. They are practically simple *cross sections* of the flowers. There are certain conventional symbols he will notice for sepal (stroke with a notch in the centre), petal (simple stroke), and stamen (cross section of anther). The ovary is just represented by a simplified cross section. The greatest care is necessary in examining flowers to make out such a point as whether a stamen stands opposite a petal or between two of them, and the like. Usually they alternate, and when the stamens are twice as many as the petals they are on two whorls. In gamopetalous corollas the petals are of course joined to one another, and in the case of epipetalous stamens a little line joins petal and stamen. The value of floral diagrams will be seen in the comparison of bluebell and grass, extreme types of the Monocotyledon group (Figs. 3, 4, Sh. IX.).

A floral formula is a convenient statement in a conventional and very brief form of the chief facts on the

structure of a flower. In the following, K is used for calyx, C for corolla, A for androecium, and G for gynoecium. A number stands for each whorl, and the number of parts in each is indicated, of course, by the number. A stroke over a number indicates that its parts cohere. A stroke above, say, the androecium and the corolla shows that the stamens are epipetalous. If the gynoecium is superior, a short stroke is placed below its number; if inferior, above. It is assumed that successive whorls alternate. If they do not, a vertical stroke is placed between the whorls which are opposite. When the parts of the flower are in a spiral, and their number is indefinite, the symbol ∞ is used. In the tetradynamous flowers (Cruciferae) there are two outer sepals, two inner, and then a whorl of four petals, which alternate with these four sepals. This is indicated by a \times between K and C. A vertical arrow shows that a flower is zygomorphic; its absence implies actinomorphic. The following examples are of common flowers, and should be verified in as many cases as possible.

Common Buttercup (<i>Flower hypogynous</i>)	$\left\{ \begin{array}{l} K 5 \\ C 5 \\ A \infty \\ G \underline{\infty} \end{array} \right.$
Marsh Marigold (often confused with Buttercups).	$\left\{ \begin{array}{l} K 5 \\ C - A \infty \\ G \underline{\infty} \end{array} \right.$
Dog-Rose (<i>Flower perigynous</i>)	$\left\{ \begin{array}{l} K 5 \\ C 5 \\ A \infty \\ G \underline{\infty} \end{array} \right.$
Hawthorn	$K 5 C 5 A \infty G \frac{1}{2}$
Pea	$K \widehat{5} C 5 A \overbrace{5 + 4}^{\downarrow} 1 G \frac{1}{2}$
Laburnum or Broom.	$K \widehat{5} C 5 A \overbrace{5 + 5}^{\downarrow} G \frac{1}{2}$
Wallflower, or Turnip, Mustard, Lady's-Smock, Shepherd's-Purse, or Virginia Stock, most Cruciferae	$\left\{ \begin{array}{l} K 2 + 2 \times C 4 \\ A 2 + 4 G \widehat{2} \end{array} \right.$
Primrose or Cowslip (Primulaceae)	$K \widehat{5} C \widehat{5} A 5 G \widehat{5}$
Sunflower, Thistle, Cornflower, Dandelion, or Daisy (fertile floret). Compositac generally.	$K \cdot C \widehat{5} A \widehat{5} G \frac{1}{2}$
Bluebell. Many other Liliaceae	$K \widehat{3} C 3 A 3 + 3 G \widehat{3}$
Parsley or Carrot (Umbelliferae generally)	$K 5 C 5 A 5 G \frac{1}{2}$

PART III.

(All these dissections should be done in a dissecting dish with a cork bottom under water.)

THE CRAYFISH.

Dissection I.—Before killing, see scaphognathite working in gill chamber. The crayfish may be held with impunity by the back. Kill by *momentary* immersion in boiling water. Examine the external characters of the crayfish, including appendages of thorax and abdomen, but leave the mouth appendages until last. Open from the dorsal side, cutting away the cephalo-thoracic shield above the pericardium, and extending opening to expose the stomach. Note bands of muscle running obliquely backward and inward to dorsal walls of abdominal somites, heart and its ostia, gonad underneath and in front of heart, stomach, liver (almost entirely hidden at first in mature females by enlarged ovary), and the great circular masses of muscle on either side of the stomach. The heart may be injected with ink or any coloured fluid, but preferably with suspended Prussian blue. Inject by means of a small canula inserted through one of the dorsal ostioles. Then examine arteries. Remove heart after this, and see the genital gland and duct (the oviduct is wide, thin-walled, and transparent, and shows as a groove upon the undisturbed liver, internal and ventral to it). Remove genital gland and duct, and clear away the muscle around the gastric mill to make out the ossicles *in situ*. See mesenteron and pyloric caecum. Cut out stomach, and see the gastric mill from within. Pick out all the soft liver, and leave the rest of the animal in spirit.

Dissection II.—Take the same crayfish, examine position of green gland and ureter, oesophagus, circum-oesophageal commissures, and supra-oesophageal ganglion. Remove terga from abdomen and dorsal muscles, to see superior abdominal artery and rectum. Remove these, and, very

carefully, the muscle that lies below them, to expose the abdominal part of the nerve chain. Now work forward, cutting away the endophragmal system, to expose the chain in the thorax.

Proceed to remove the appendages from one side, working from the sixth abdominal forward, and arrange them in order on a sheet of paper. Cut off the relics of the branchio-stegite, to expose gills. In removing the thoracic appendages, take care to get off the podobranch therewith, in cases where it occurs. Compare this with an arthrobranch. See also the pleurobranch. Be careful not to mix the mouth appendages as you remove them. See the papilla of the green gland, and the auditory cyst.

THE EARTHWORM.

Dissection.—Kill by chloroform, and transfer to alcohol, or drown in alcohol. Open along mid-dorsal line, and make out all the chief organs. Examine fragments of nephridia, cuticle, and setae in water, under low power. From a good-sized specimen, having the clitellum and spermathecae well marked, get out the ovary. To do this, count back (the spermathecae form a convenient landmark) to segment thirteen. Push intestine to one side, and pin the segment out to stretch it widely open. Remove the dissection from the water, and wash repeatedly with alcohol. The ovary becomes white and much more distinct. It is about a twelfth or fifteenth of an inch long, and attached to the anterior wall of the segment. Transfer it by means of forceps to a glass slip, and examine under the low power. Its appearance should be exactly like our figure. Do not deceive yourself with coiling bits of nephridium. Look for the distinct round eggs, *and see that you get them.* Look also for oviduct and for funnels of *vasa deferentia*.

THE MUSSEL.

Dissection I.—Kill by *momentary* immersion in boiling water. Mussels, it is said, are occasionally dissected alive, and the heart, arteries, and auriculo-ventricular valve are then more easily seen. Open by removing the *left* shell, and

work from *left* side, as this is better for the dissection of the alimentary canal. Cut through adductors, but take care not to injure mantle. Make out position of liver, kidney, and organ of Keber, inhalent and exhalent openings. Although the reverse is implied in some text-books, this is the most convenient stage for seeing the cerebral ganglion. Look at the ventral end of the line of contact of the adductor and liver, and just in front of the anterior retractor, and a reddish spot of colour will be seen. This is not the ganglion, but it is due to the orange colour of the ganglion showing through the half-transparent tissue of the mantle. Pick into this half-transparent tissue with a needle. The ganglion, when exposed, is triangular, and the supra-oesophageal, cerebro-pedal and cerebro-visceral commissures are seen very distinctly at its angles. Cut off mantle and see gills. Remove gills and see genital and urinary openings (see Fig. V., Sh. XVIII.). Open pericardium to see auricle, ventricle, rectum, and nephridium (Fig. I., Sh. XIX.). Cut away auricle and see nephrostome. Cut into ureter and see inter-renal opening. Cut into secretory part of kidney and see left cerebro-osphradial commissure. Trace it back over the posterior retractors, and (cutting away all that is left of gills) to the osphradial ganglia, which lie ventral and a little posterior to the posterior adductor. Run a seeker up the rectum.

Examine, if time permits, bits of the gill with the low power. Splendid cilia can be seen by scraping a few cells from the gills of a living or recently killed mussel. Sometimes the outer gills of the female will be found to be very greatly distended with a reddish granular substance, the *glochidia*, which may be examined under the low power. Parasitic infusoria and arthropods often occur on the gills of the mussel. Leave the remainder of the mussel in spirit.

Dissection II.—Take the remains of the above mussel after some days' immersion in spirit (dissecting from the left side), and cut off the greater part of the foot. Split what is left in the median plane, and *continue the splitting a little way into the visceral mass*. In this way it is impossible *not* to find the pedal ganglion. Now slice off the liver, cutting on a plane parallel to the median plane of the animal until

you get into the stomach. Run a seeker into the oesophagus, and then into the intestine. Follow up the seeker to the first loop, then work back from rectum to last loop, and so expose as in Fig. 8, Sh. XVIII. This dissection is a little more difficult perhaps, but quite possible with fresh material.

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